SURGEON-FRIENDLY 3D NAVIGATION

Bridging the Gap between Conventional Medical Imaging and Holographic Technology

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Master Thesis
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MSc. Design for Interaction
Specialisation Medisign

September 2023

Preface and Acknowledgements

I'm very pleased to present to you "Surgeon-friendly 3D Navigation: Bridging the Gap between Conventional Medical Imaging and Holographic Technology", which rounds up my experience as a master's student at the Faculty of Industrial Design Engineering at the TU Delft.

This thesis investigates the dynamic context of surgical planning in the medical care pathway of pancreatic cancer and focuses on designing a navigation system for three-dimensional technology revolving around the needs of surgeons. The challenge of implanting modern technology into established medical practices through design was my driving motivation behind this work. I am honoured to have had the opportunity to contribute to a field with great potential to positively impact the lives of highly skilled professionals, and very thankful to have had the opportunity to apply the knowledge from the Design for Interaction master's in the health technology industry at Philips' Experience Design.

This thesis wouldn't have been possible without the support of many remarkable people.

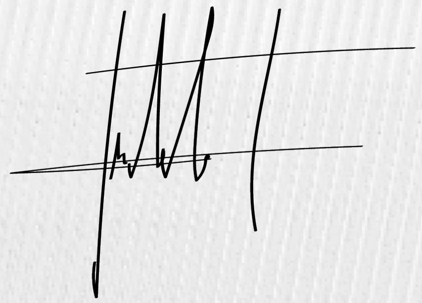
First and foremost, I want to wholeheartedly thank my academic supervisory team, Dr. Evangelos Niforatos (Chair) and Dr. Maarten Wijntjes (Mentor) for their expert guidance, reliable supervision and positive atmosphere provided above and beyond during the project. Your feedback and support have been essential throughout this journey.

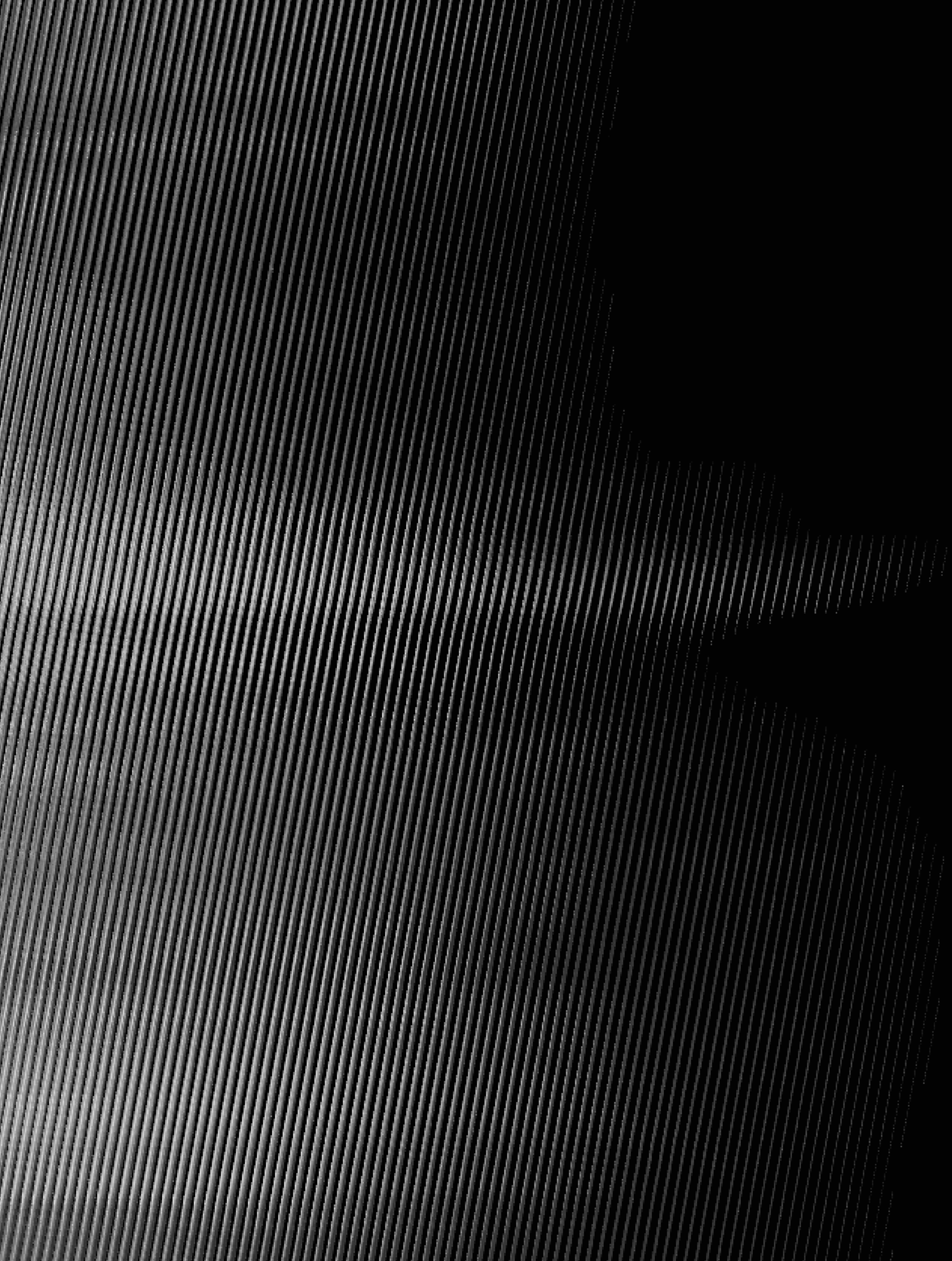
I am deeply thankful to Luc Geurts, who provided daily supervision at Philips, his expert insights, and his knowledge and passion for the project were truly inspiring. I extend my appreciation to Jon Pluyter, Harold Peeters and all the coworkers from Philips who welcomed me into their team and helped me with constructive feedback.

This endeavour would not have been possible without the support and invaluable input of Mark, who patiently enabled the connection with the surgeons and medical personnel of the Catharina Ziekenhuis Eindhoven and e/MTIC, to which I extend my gratitude for their precious time put at disposal for the project.

Finally, I want to thank my family and friends, who stood behind me throughout this adventure and helped me piece the puzzle together. In particular Flóra for your layout skills; Gabriel for quality proofreading; Nicole for your long-distance support; Kamran for your illustrative flair, Lilly for your great graphics and Dafne for the daily amount of motivation and laughter.

I wish you a pleasant read.





Summary

Hepatopancreato-biliary (HPB) surgeons, when planning complex cases of pancreatic cancer, lose precious time because of difficulties in visualising the interaction between tumour and blood vessels and identifying patient-specific anatomy. To tackle this issue, the Integrated Imaging Workstation (IIW) was prototyped by e/MTIC and Philips. This prototype encompasses a conventional medical viewer and a holographic display to visualise the same medical data, providing a functional basis and showing promise. However, it lacks a human-centred interaction design, particularly in integrating it into a surgeon's established interaction flows with conventional medical imaging, as a study with 13 expert surgeons highlights. The literature review and empirical research show that surgeons iteratively scroll through scans to build a mental 3D reconstruction of the anatomy, and have two personal approaches to finding anatomical landmarks and interactions, "vertical scan" and "zoom in and out". Also, it unveils 3 key design opportunities: minimising workflow disruption, visualising both overview and detail and balancing speed and control in the interaction.

These findings were translated into multiple design concepts, such as one with different modes of visualisation depending on anatomical landmarks. The most desirable concepts were combined into a navigation system, which in turn went through one expert feedback iteration. The final design comprises a system for surgeons to easily select anatomical landmarks through 2D medical imaging. This enables reaching and controlling desired points of view, which then can be orbited around. A high-fidelity prototype was implemented with Unity3D and evaluated. The mixed-method evaluation study with 3 expert HPB surgeons shows promise towards the overall usability of the navigation system and its clinical application. However, some aspects of the interaction, such as the selection of minor vessel branches and missing visual feedback for point-of-view changes, need refinement. These results illustrate a solid human-centred design direction for supporting surgeons in finding crucial landmarks and vascular interactions, as well as an approach to integrate 3D medical visualisation into established workflow with 2D imaging of HPB surgeons.

This thesis hopes to be a starting point for future iterations of the IIW. For example, using metaphors to help the surgeons establish a mental model of the 3D camera system could be tested, or scoping the main user focus to novice surgeons could be helpful to refine the design. Furthermore, this project could be relevant for other research and design endeavours that aim to inject 3D medical visualisation technology into existing workflows in a surgeon-friendly manner.

Keywords: Pancreatic cancer, *hepatopancreatic-biliary surgeons, medical imaging, oncology, 3D navigation, holographic display, human-centred design.*

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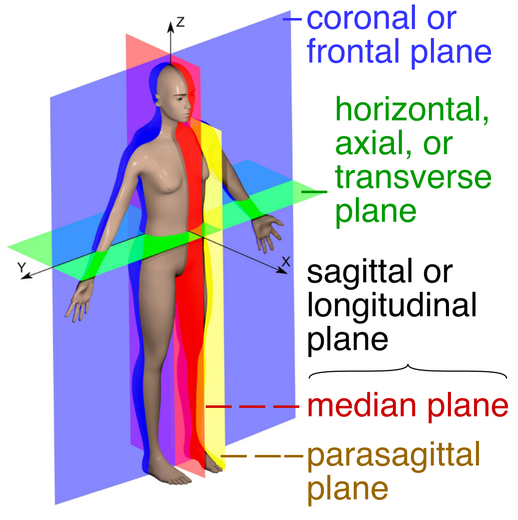
Abbreviations and Definitions

Anatomical Landmark	In this context, an identifiable part of the inner anatomy, such as a vessel or an organ.
AR /VR	Augmented Reality / Virtual Reality
CAD	Computer Aided Detection / Diagnosis
CT scan	Computed Tomographic scan, a medical imaging technique
CZE	Catharina Ziekenhuis Eindhoven
DICOM	Digital Imaging and Communications in Medicine
DPCG	Dutch Pancreatic Cancer Group
e/MTIC	Eindhoven Medical Technology Innovation Center
HCI	Human-Computer Interaction
HMD	Head-mounted Displays
HPB surgeon	Surgeon specialised in the Hepatopancreato-biliary or the abdominal region
IIW	Integrated Imaging Workstation, the prototype from Philips
MDT Meeting	Multidisciplinary team meeting
Patient-specific Anatomy	In this context, the personal inner anatomical composition organs, which might have deviations from the common anatomy
Tumour-vessel Interaction, vessel ingrowth	The expansion of a tumour into a vessel.

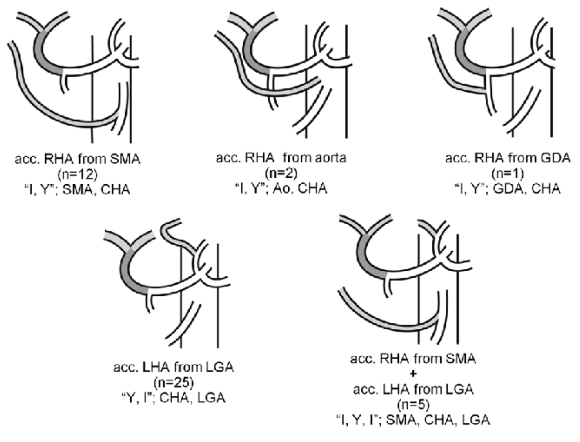
Medical Visual Glossary

ANATOMICAL PLANES



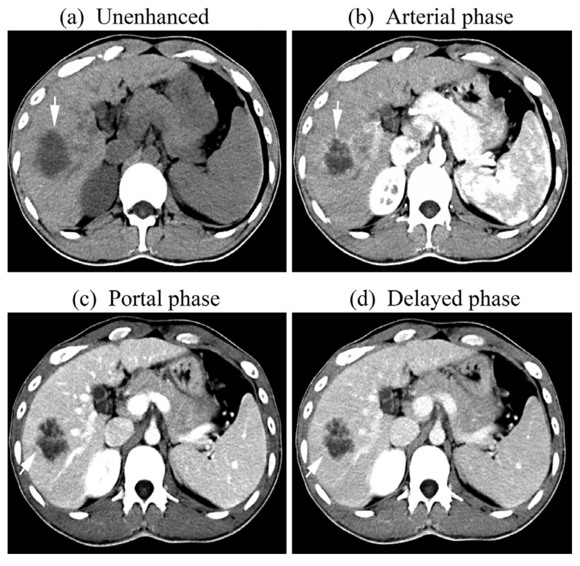
In human and animal anatomy, an anatomical plane is an imaginary reference plane used to describe the body's structures and movements. Three main planes are employed for this purpose: the sagittal plane divides the body into left and right halves, the coronal plane separates the body into front and back sections, and the transverse plane splits the body into upper and lower parts. (Illustration from Wikipedia, https://en.wikipedia.org/wiki/Anatomical_plane)

ANATOMICAL VARIATION



Anatomical variation, anatomical variant, or anatomical diversity refers to a presentation of bodily structure that deviates from the typical description found in the majority of individuals. For instance, in this context, an aberrant right or left hepatic artery represents an anatomical variation in the vascular supply of the liver. Anatomical variations are part of patient-specific anatomy. (Illustration from Kobayashi, S., et al., 2014)

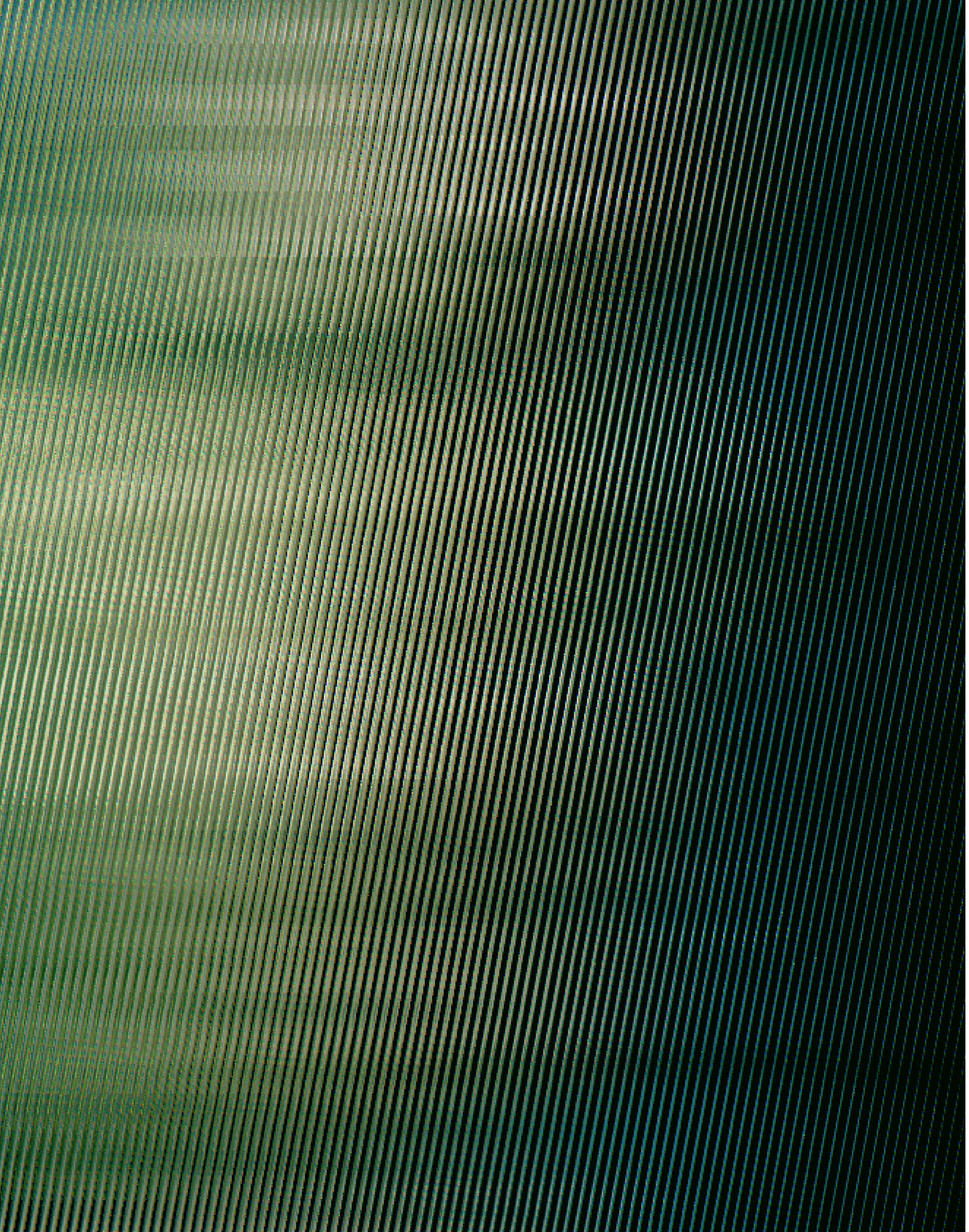
CT SCAN PHASES



Phases Abdominal CT scan phases, specifically the arterial and portal venous phases, are distinct stages in which contrast dye is used to enhance the visualization of abdominal structures. The arterial phase captures images of arteries, offering insights into blood flow and vascular conditions, while the portal venous phase focuses on visualizing the liver, spleen, pancreas, and other abdominal organs, aiding in the detection of lesions and overall organ assessment. These phases are essential for precise diagnoses and evaluations of abdominal conditions. (Image from Li, R. et al., 2016)

TUMOUR-VESSEL INVOLVEMENT

Tumor-vessel involvement, or tumour-vascular interaction, or ingrowth, describes a scenario in which a tumor extends into a blood vessel. Whether the tumor can be treated surgically depends on the degree of invasion into the vessel, and this determination is guided by the resectability criteria established by the DPCG, as illustrated in the accompanying picture. (Illustration from Ruijs, L., 2022)



CHAPTER 01

INTRODUCTION

This chapter presents an overview of the clinical workflow of pancreatic cancer and introduces the work that was already done by the project partners of Eindhoven MedTech Innovation Center (e/MTIC). Then, it exposes the challenges of the context to be tackled and introduces the research questions.

Introduction

// Why Pancreatic Cancer

Pancreatic cancer is among the deadliest cancers worldwide (McGuigan, A. et al., 2018). The Netherlands Comprehensive Cancer Organisation (IKNL) reports a greater incidence among older individuals and males, and often late-stage diagnosis. This is reflected in the low, up to 5-year survival rate for less than 5% of the patients and raises the challenges of early detection and effective treatment options (IKNL, 2022). The pancreatic head is the most commonly affected region (Jaffee et al., 2002), which in 15-20% of the patients (LUMC, 2022) can be treated with the Whipple surgery (Figure 1). If the tumour has already spread to other organs (metastasis) or considerably expanded into a vein or artery (blood vessel ingrowth), palliative treatment is opted for.

In addition to this demanding context, the clinical workflow that medical practitioners undergo is not always straightforward. In complex cases with reduced blood vessel ingrowth (See Medical Visual Glossary), Dutch surgeons and radiologists rely on the criteria established by the Dutch Pancreatic Cancer Group (DPCG, 2012) and their experience to make time-consuming decisions (Rasenberg, 2021). To gain insight into the complexity and the various challenges faced by medical practitioners in the pancreatic cancer workflow, it is crucial to comprehend the pivotal decision-making moments throughout the treatment process of pancreatic cancer and the key medical stakeholders involved. The simplified chronological phases (Figure 2) described in this paragraph are based on practices observed at Catharina Ziekenhuis Eindhoven (CZE) (D. Rasenberg, 2021), highlighting challenges that arise in this context.

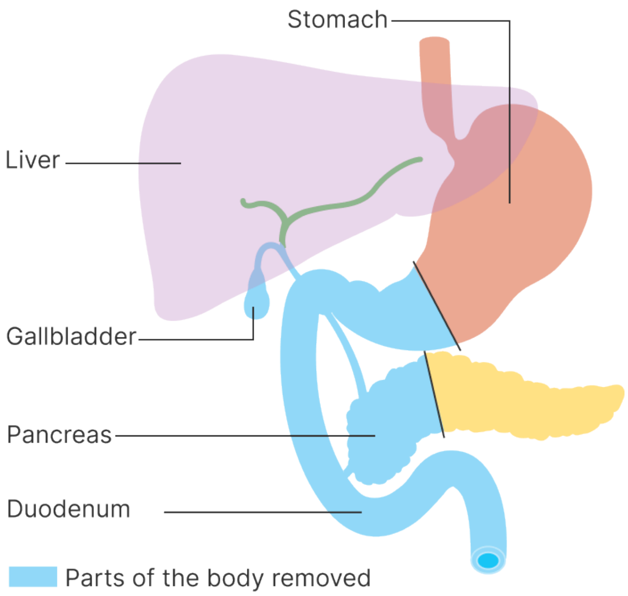


Figure 1. Whipple Surgery, or pancreaticoduodenectomy. The blue part is removed, as the tumour resides in the head of the pancreas. The organs are then connected through the small bowel. (Image: Wikipedia)

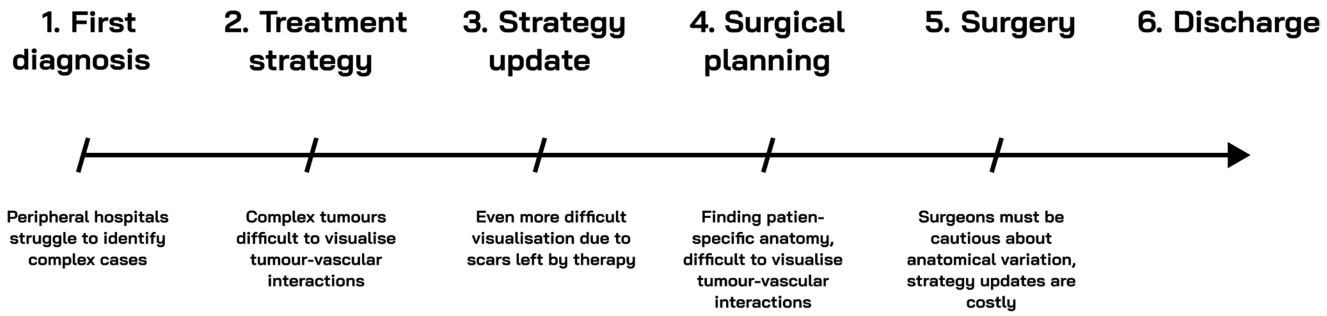


Figure 2. Timeline of clinical workflow with associated challenges per phase.

1. First diagnosis:

The workflow typically begins with a referral of a patient from a peripheral hospital, usually by a gastroenterologist. Diagnostic imaging is examined in the so-called multidisciplinary team (MDT) meeting, which often includes a hepatopancreato-biliary (HPB) surgeon, a radiologist, a vascular surgeon, a gastroenterologist, and an oncologist. In this session, the patient's CT scan, specifically the pancreatic regions, is reviewed with the goal of assessing if the tumour is treatable.

Challenges: Peripheral hospitals, with less expert medical personnel, struggle to identify complex cases.

2. Diagnosis Refinement and Treatment Strategy:

Once a patient is considered treatable, a second MDT meeting takes place involving the same core medical staff, sometimes extending to other experts. This time, the team aims to determine whether the tumour is resectable (can be surgically removed) and analyses the CT scan in combination with other information such as blood tests. Three outcomes can emerge from this discussion: if the tumour is resectable, the treatment can be surgical. If it is borderline resectable, the patient needs to undergo neoadjuvant therapy (chemotherapy that aims to reduce the tumour's size), and if it is unresectable, palliative care has to be provided.

Challenges: When dealing with complex tumours, visualising the vascular structures and interactions is difficult with conventional medical imaging, especially for less experienced medical practitioners. Also, discussions about reseactability take up a lot of valuable time.

3. Treatment Planning for Borderline Resectable Tumors:

In cases of borderline resectable tumours, neoadjuvant therapy is performed to reduce the tumour in size. Following the therapy, new scans are generated to assess the tumour's response, and based on the findings, the practitioners may decide to repeat the neoadjuvant therapy, proceed with surgical resection, or provide palliative care.

Challenges: This process often reduces the visibility of the tumour on medical imaging due to the cicatrices it leaves on the healthy tissue, making clinical examination even more difficult.

4. Surgical Planning / Pre-operative Preparation:

Once the decision is made to proceed with surgical resection, surgeons have to determine which type of operation is suitable: open, laparoscopic, or robot-assisted surgery, which is chosen based on each patient's case. The specific type of surgery performed, such as the Whipple surgery (also called pancreatoduodenectomy), is determined by the tumour's location. Medical imaging is consulted again to meticulously plan the surgery, taking into account how to get to and resect the carcinoma, identifying possible complications, and patient-specific anatomy to consider during the upcoming operation.

Challenges: Visualising patient-specific anatomical structures and tumour interactions is particularly difficult for complex cases. No depth perception is available with conventional medical imaging.

5. Surgery:

The surgical team starts by performing laparoscopic inspections, to assess if the chosen plan is viable or has to be changed. Then, the surgeon moves towards the tumour and prepares the surroundings for the resection. Then, the pancreatoduodenectomy f.e., is performed. The CT scan is often present in the operating room, providing a reference for the surgeons in making decisions or ensuring adherence to the surgical plan.

Challenges: During the surgical procedure, the surgeon must be extremely cautious to avoid damaging surrounding organs and vessels. When the surgical strategy needs to change (i.e., because of abnormalities not seen during *planning, or the vessel involvement was misjudged), precious operation room (OR) time is lost and raises the risk of surgery.*

6. Discharging Patient and Palliative Care:

If no signs of disease progression are found during the postoperative period, the patient is discharged. In cases where the tumour is unresectable or disease progression occurs, the patient may be directed towards palliative care, which aims to improve the length and quality of the remaining life.

// Project partners: What is currently being done

This graduation project exists because of the e/MTIC oncology project, a partnership between Philips, CZE, and Eindhoven University of Technology (TU/e). This multi-disciplinary team seeks to accelerate human-centred clinical innovations in oncology care, specifically for pancreatic and lung cancer, by leveraging the potential of artificial intelligence (AI) for computer-aided detection and diagnosis (CAD). Graduates and PhDs from different universities are involved to support the core team with the research and development of the project.

The emphasis on pancreatic cancer is relevant because, as depicted in Figure 2, the oncological team continues to encounter significant challenges in the clinical workflow, particularly in complex cases. The most critical issues are associated with medical visualization, decision-making, and adapting strategies. These problems appear to be more pronounced among less experienced practitioners and often result in substantial time delays and reduced confidence in case assessments (Rasenberg, 2021). This underscores the potential for workflow improvement.

To address the aforementioned challenges, e/MTIC designed a prototype. After two years of project development, they created the Integrated Imaging Workstation (IIW), which integrates AI and 3D technology to address the difficulties faced by medical practitioners at CZE.

The IIW utilizes the standard Picture Archiving and Communication System (PACS) and builds upon the existing functionality of conventional Digital Imaging and Communication in Medicine (DICOM) viewers (Figure 4). A DICOM viewer typically offers basic image manipulation capabilities and is used to visualize different phases (see Glossary G) simultaneously.

The IIW is built on two main features. Firstly, the AI-powered tumour-detection CAD tool: a layer of AI-generated segmentations of vessels, organs and tumours (Figure 3, coloured outlines) is added onto conventional imaging. In the case of vessel ingrowth, an analysis of the involvement is proposed on the side panel. Secondly, an external autostereoscopic display to enhance the visualisation of the patient's anatomy through a realistic 3D representation (Figure 3). This display, the Looking Glass Landscape, uses the same segmentations generated for the 2D viewer and can be interacted with through a regular mouse with a 3D pointer. Using the broadly used game engine Unity3D, it supports changing the opacity of specific elements, saving camera viewpoints, and zooming and can mostly be navigated with a "click-and-drag" mouse interaction.

The choice of an autostereoscopic display was made for several reasons. Autostereoscopic displays, categorized under mixed reality (MR), offer users the ability to experience 3D visuals without requiring additional headwear (Goddard T., 2020). They provide both stereo parallax (where each eye sees different images) and movement parallax (where moving the head reveals different images) cues. For instance, the Looking Glass provides 45 different views from various angles to each eye, enabling medical practitioners using the IIW to perceive depth when assessing a case. Additionally, during MDT meetings, multiple doctors can simultaneously view the 3D model from their respective perspectives.

Figure 3. Integrated Imaging Workstation. Prototype developed at Philips, on the left an AI - segmented DICOM viewer, on the right an autostereoscopic display, with a 3D representation of the scan on the 2D viewer (Image courtesy of Philips Experience Design).

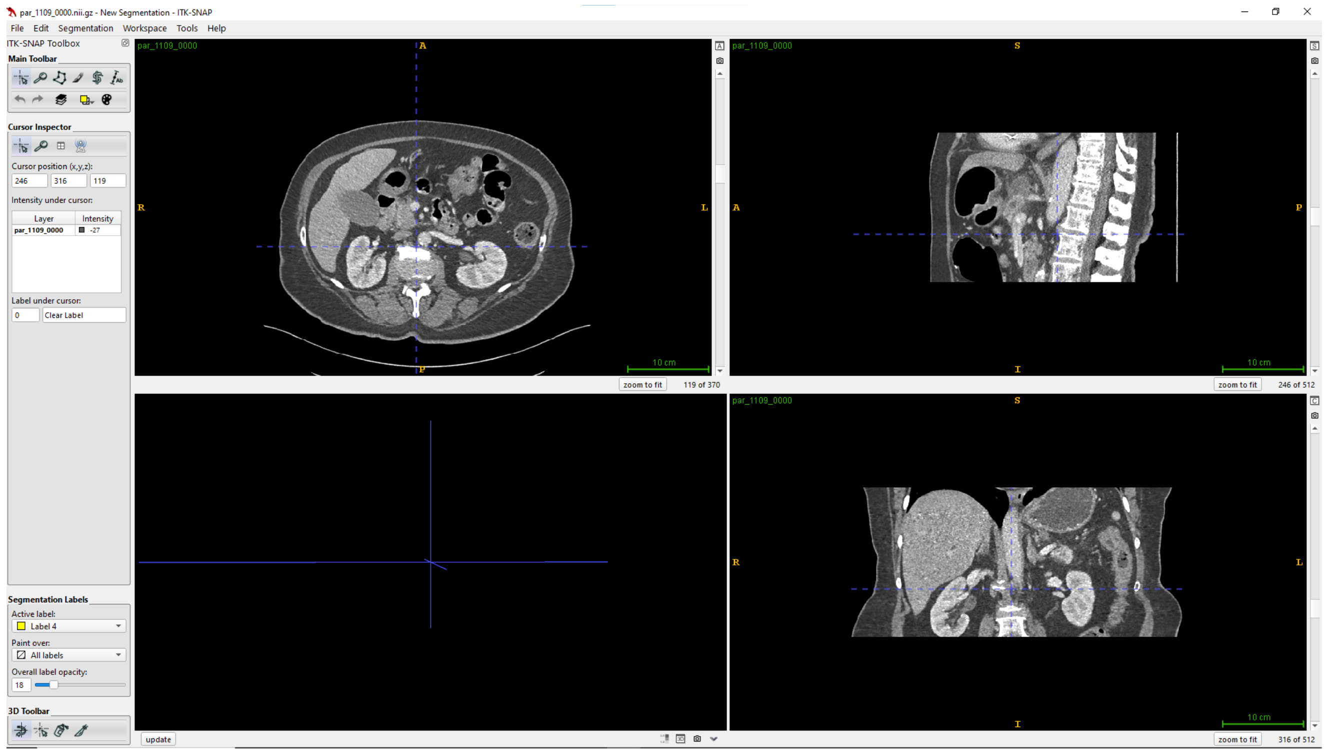


Figure 4. ITK-Snap, a freeware conventional DICOM Viewer A CT scan from different anatomical planes (see Medical Visual Glossary). (Screenshot)

// Scoping the problem: Surgeons and Surgical Planning

The IIW has the potential to improve a variety of problems in the clinical pathway and could be operated by a variety of medical doctors, even in the presence of patients for consultations. But who are the principal users of this technology? Two stand out, radiologists and surgeons.

Radiologists assess cases, annotate relevant information on the scans, and provide thorough reports for the HPB surgeons who will perform the surgical interventions (Preim, 2011). The radiologist's expertise and contributions to the decision-making process within the MDT meetings significantly influence the accurate diagnosis and optimal treatment planning for patients with pancreatic cancer. As they predominantly work with medical imaging, they profit mostly from the AI-segmentation feature of the IIW (Rasenberg, 2021).

HPB surgeons assume various responsibilities throughout the treatment process, some overlapping with the radiologists'. They need to understand the patient's condition, they participate in MDT meetings to discuss the diagnosis and select optimal curative treatments. Surgeons crucially plan and perform different kinds of surgeries, and evaluate post-surgical outcomes. They also work with medical imaging but with a different mindset, as they have to deal with the practical implications of the operation room (Preim, 2011). Because they need to acquire a comprehensive understanding of the patient's anatomical features and mentally reconstruct a representation, they profit prevalently from the 3D visualisation feature of IIW (Rasenberg, 2021).

This thesis, following a human-centred approach, commits to focusing on surgeons as the principal stakeholders, because of their extended involvement in the workflow and the higher ceiling for improvement of their practice with the IIW.

Observing the medical workflow from a surgeon's perspective, the phase of surgical planning (or preparation) emerges as the most challenging when using medical imaging, especially when considering complex cases of pancreatic cancer. This is because of the need to memorise the patient-specific anatomy and plan how to navigate to the tumour in minimal detail. The stakes are high, as imprecise planning will end in intraoperational surgical strategy changes (Preim, 2011), misusing precious operation time. For this reason, this is also the moment where the prototype can make a difference thanks to the enhanced visualisation of vascular structures and interactions and the depth perception it offers.

// The Problem & Research Questions

While the prototype already provides a functional basis and shows promising results, there is still room for improvement in user interaction with the 3D aspect, which is crucial for successful integration into daily practice. The interaction with the anatomy on the autostereoscopic display is in its early stages and lacks a human-centred integration into surgeons' existing workflow. This is supported by a pivotal user study conducted with medical experts on the Integrated Imaging Workstation by Rasenberg (2021) and later scrupulously analyzed by Ruijs (2022). Surgeons often did not engage with the autostereoscopic visualization, sometimes not even realizing that interaction was possible.

This thesis aims to zoom into the process of surgical planning and understand the complexity and richness of the current interactions of the surgeons with medical imaging, to design a system that enables navigation of the 3D tailored to their current workflow. This brings to the following questions, divided into two pillars of contextual research and interaction design part, which will be answered in the scope of this thesis.

Context

RQ1: How do surgeons use medical imaging for surgical planning?

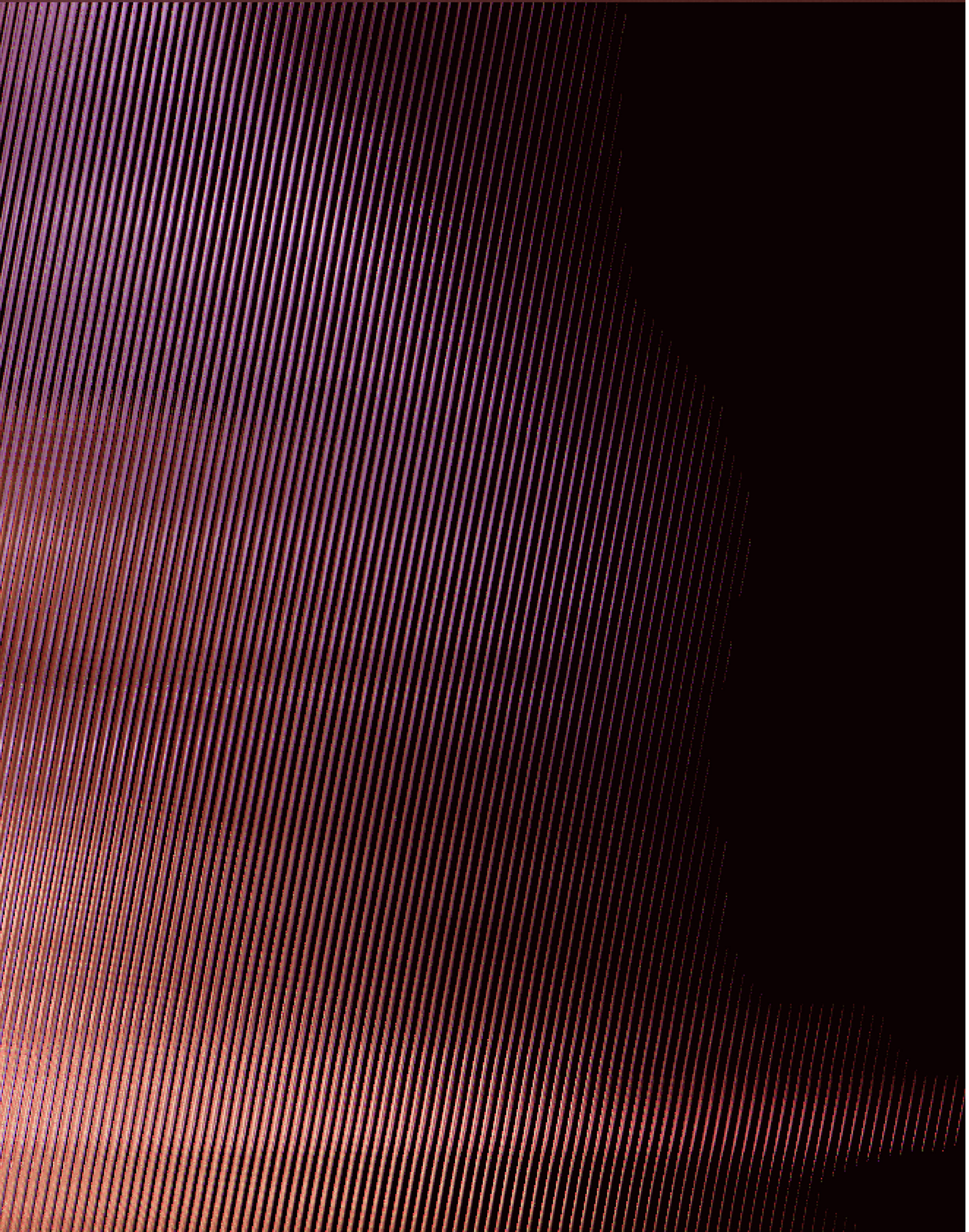
RQ2: How do they approach finding anatomical landmarks and tumour-vascular interactions?

Design

RQ3: How can one design a 3D navigation system to support surgeons in finding crucial anatomical landmarks and tumour-vascular interactions?

RQ4: How can one seamlessly integrate 3D medical visualisation into conventional 2D medical imaging?

Anatomical landmarks: In this context, organs and vascular structures in different points or junctures, any interesting or relevant point of the inner anatomy.



CHAPTER 02

APPROACH

This chapter offers a brief overview of the methods employed during this project, mapping them out in chronological order.

Approach: Research & Design

This project is rooted in human-centred design practices and the research-through-design methodology (Stappers & Giaccardi, 2017; Zimmerman et al., 2007). These approaches involve an iterative process of prototype development aimed at comprehending complex situations and continuously reassessing them (Stappers & Giaccardi, 2017). The project encompasses multiple divergence-convergence iterations (Banathy, 1996) throughout its progression (Figure 5).

Initially, extensive research into the context, workflow, and interactions of surgeons with medical imaging was conducted through a comprehensive literature review encompassing both medical and interaction fields. This was followed by a questionnaire and two expert interviews to gain a more human-centred perspective of the context. The collected data was then subjected to thematic analysis (Braun & Clarke, 2006), revealing critical challenges, answering part of the research questions, and generating actionable design opportunities.

Building upon the research findings and a co-creation session (Sanders & Stappers, 2008) that employed creative ideation techniques, various navigation and surgeon-friendly concepts were developed to address the identified central issues. These concepts underwent two feedback iterations. The first involved an expert assessment of desirability, guiding the implementation of a prototype embodying the most promising directions. The second iteration used
the initial prototype as a probe to refine the understanding of the essential design qualities for surgeons and the design's key features. The feedback gathered during this phase was integrated into a final prototype.

A conclusive mixed-method (Creswell, J. W., 2008) evaluation study, combining a SUS questionnaire, clinical assessment questions, observation, and open questions, was conducted with surgeons to assess the usability and potential clinical value of the prototype. The data was analysed by computing the SUS scores and employing thematic analysis (Braun & Clarke, 2006). Based on the results of this evaluation, the research questions were answered, and recommendations for future improvements to the prototype, along with guidelines for both design and research, were presented.

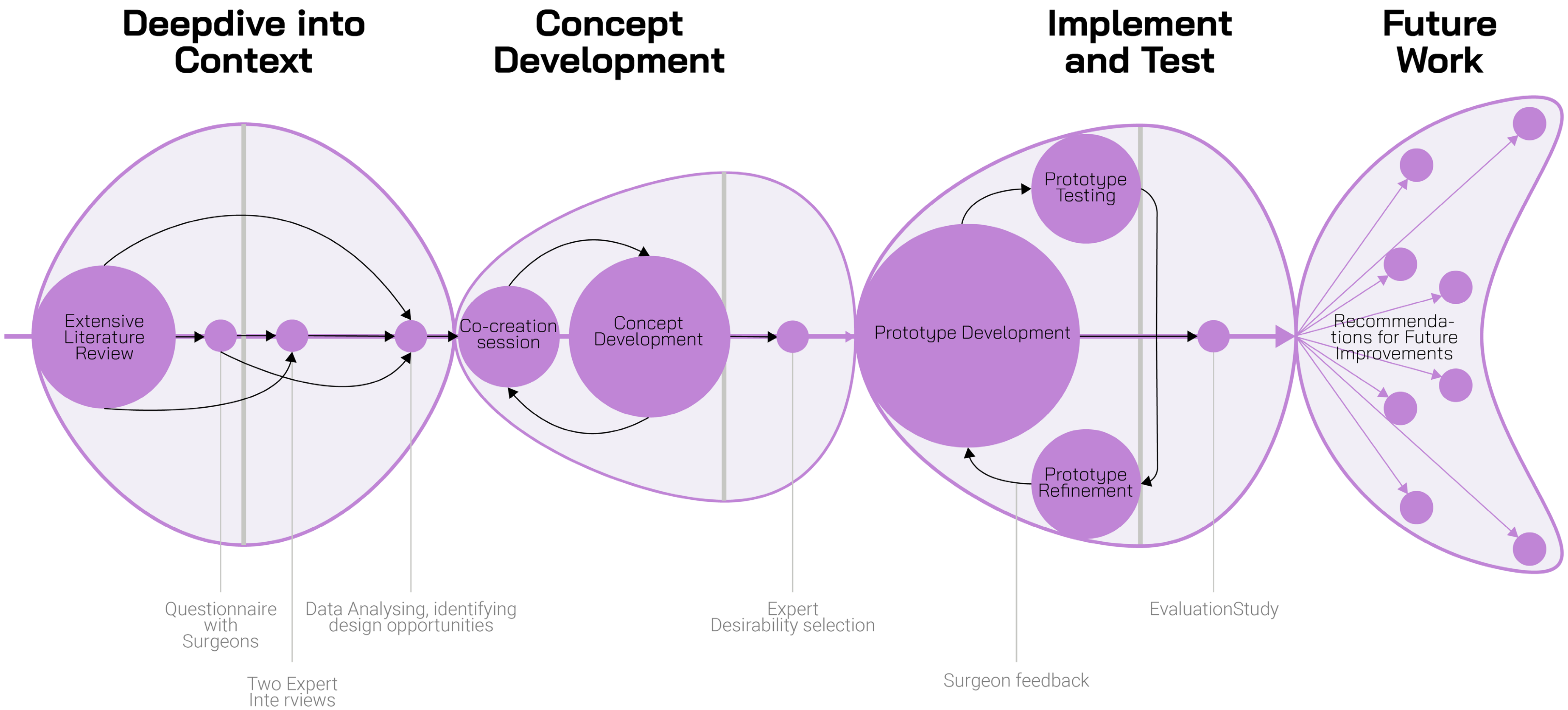
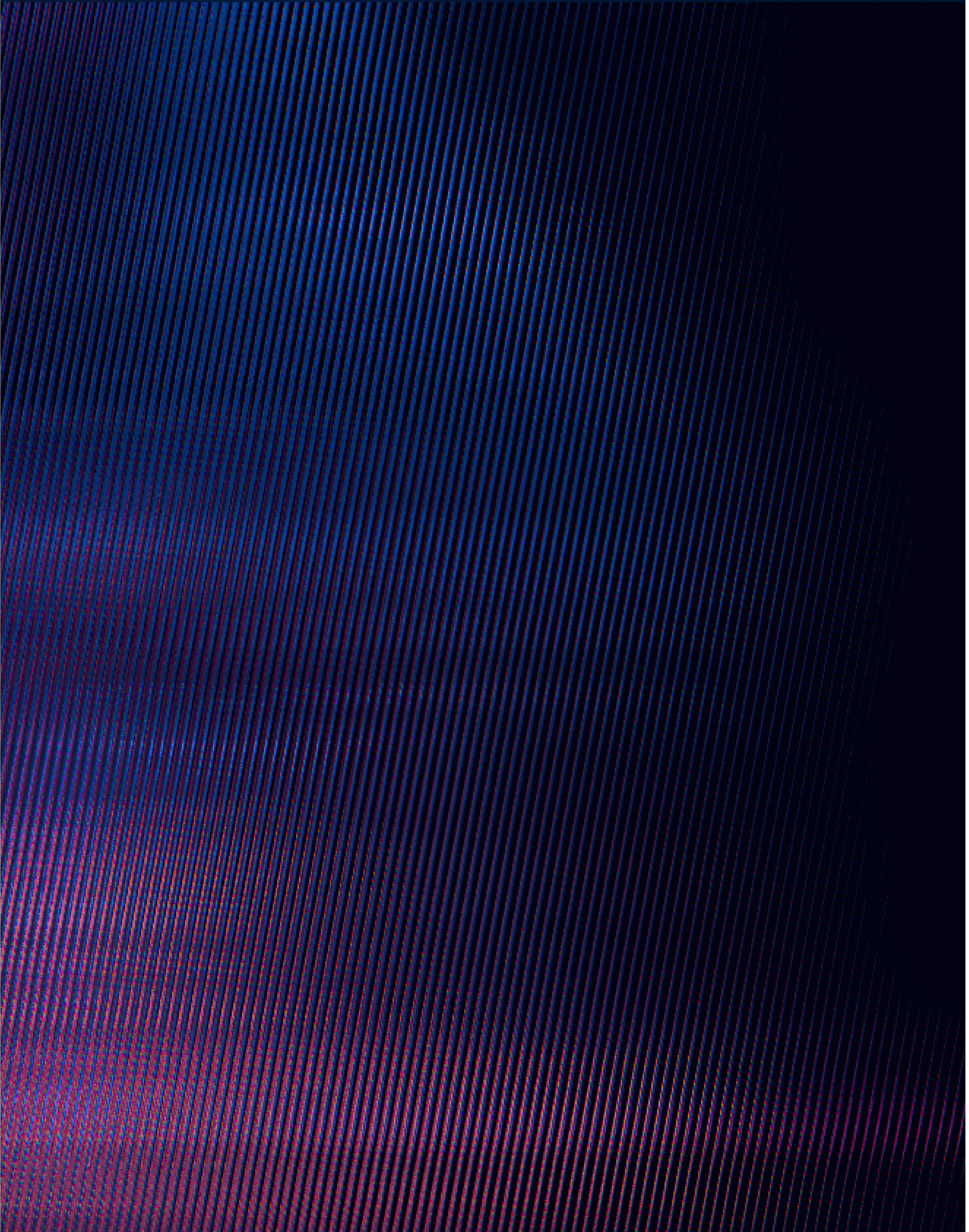


Figure 5. Visual overview of the design process



CHAPTER 03

MEDICAL LITERATURE REVIEW

This chapter first introduces related work in the context of surgical planning, highlighting the overarching insights and challenges arising. Then it presents Preims' (2011) relevant guidelines for the design and research of medical visualisation from a Human-Computer Interaction (HCI) standpoint.

Medical Literature Review

// Current research and application of 3D technology in oncology

Promising directions

The most prominent research trends in 3D technology in oncology are as follows: collaborative surgical planning with immersive technology as the majority, real-time digital overlays during surgery, and simulation of the abdominal region.

The first trend, collaborative surgical planning, aims to improve interaction during MDT meetings using immersive technology to enhance shared understanding among medical professionals. Bashkanov et al. (2015) utilized VR headsets for data visualization, reducing ambiguity and enhancing surgical planning. Boedecker et al. (2021) introduced an easy-to-learn VR approach for preoperative liver surgery planning, while Kenngott et al. (2022) emphasized the effectiveness of VR in complex liver surgery planning. Kumar et al. (2022) investigated AR head-mounted displays (HMD) and found potential benefits for MDT meetings in complex cases compared to conventional imaging.

The second research trend focuses on real-time digital overlays during surgery, primarily aimed at enhancing medical accuracy in locating tumours and vessels. Okamoto et al. (2014) reviewed the clinical use of AR-based navigation surgery in the abdomen, highlighting its value in hepatobiliary and pancreatic surgery with laparoscope cameras. Sauer et al. (2017) assessed MR technology for displaying 3D models during liver surgery, with challenges related to accurately superimposing models, especially in the HPB region.

The third research direction involves planning with simulation. Uchida (2014) explored 3D imaging simulation of the abdominal region during surgery using VR. Takamoto et al. (2013) highlighted the accuracy and time-saving benefits of 3D simulation in liver surgery planning. While Hallet et al. (2015) acknowledged the utility of simulation in hepatectomy planning, they advocated for further research. Oshiro & Ohkohchi (2017) emphasized the significance of 3D preoperative simulation for safer liver surgery.

Notably, in this reviewed literature, there is no mention of a system similar to the IIW, which combines a DICOM viewer with autostereoscopic technology, nor an alignment with surgical planning and preparation as an individual activity performed by surgeons.

Input systems and manipulation of the 3D

Concerning the different input systems were used: two-handed interaction joysticks for VR HMD (Bashkanov et al., 2015; Boedecker et al., 2021), mouse combined with head movements detected through the VR HMD (Kenngott et al., 2022), hand gestures tracked by an AR HMD (Fitski et al., 2020; Kumar et al., 2020).

Manipulation of the 3D models found, on the other hand, is comparable to one of the IIW. This includes moving, rotating, scaling and turning models on/off (Fitski et al., 2020; Boedecker et al., 2021; Kenngott et al., 2022; Kumar et al., 2020; Bashkanov et al., 2015). Some implemented a way to control opacity, usually with a 2D widget (Boedecker et al., 2021; Kumar et al., 2020). Boedecker et al. (2021) system affords the user with annotation of resection lines on the surface of the liver, while Kenngott et al. (2022) implemented a system to switch between different preset views and change between patient cases. Kumar et al. (2020) designed a contextual panel with different widgets to control 3D models.

Strengths of 3D in oncology

3D medical visualisation performed better than conventional 2D scans in visualising interactions between anatomical and pathological structures (Bashkanov et al., 2015; Endo et al., 2007; Oshiro & Ohkohchi, 2017; Preim, 2011; Uchida, 2014). 3D visualisation was deemed effective for complex cases, which were tougher to interpret in 2D (Kenngott et al., 2022; Kumar et al., 2020; Radtke et al., 2010). Further, various researchers (Fitski et al., 2020; Kenngott et al., 2022; Marescaux et al., 1998) mention the advantage of 3D representations in enhancing finding patient-specific anatomy. Seeing anatomic vari was considered particularly important in HPB operations because the deformability of organs in the abdominal region makes imaging interpretation and surgery more complicated (Nguyen & Melstrom, 2020; Okamoto et al., 2015; Oshiro & Ohkohchi, 2017; Uchida, 2014).

These findings align with the goals of the prototype, highlighting the importance of using 3D to help surgeons find patient-specific anatomy and anatomical interactions, especially for complex cases and in the HPB region.

Gap in Research

This initial review revealed a lack of focus on individual surgeon planning, limited use of autostereoscopic displays with keyboard-mouse interaction, a scarcity of interaction design guidelines, and limited human-centred research. These findings prompted an extension of the scope of the literature review to include papers that address these crucial aspects, as presented in the next section.

// An HCI perspective in medical visualisation

This section builds upon the previous segment by incorporating the designer's perspective, drawing from the extensive experience of Bernhard Preim, who has dedicated over two decades to researching medical visualizations in the context of Human-Computer Interaction.

Visualisation tasks

In particular, the following tasks performed by healthcare professionals (Preim, 2011) are invaluable when designing interactions for medical visualisation.

Navigating a path inside long branching structures like airway trees or vascular systems to understand their branching patterns and identify wall abnormalities; examining the immediate vicinity of pathological structures; analysing potential resection areas and resection planes (See medical glossary); and integrating information from diverse sources, including medical scans and patient documents.

The first two points are particularly relevant in the context of surgical planning, as they pertain to the identification of patient-specific anatomy and the examination of vessel interactions.

Key considerations

In optimizing medical visualization systems, several key considerations are emphasized. Firstly, the importance of tailoring displayed anatomical information to the practitioner's specific requirements is highlighted, particularly in cases involving infiltrations or ingrowth (Preim, 2011). Secondly, implementing default settings that align with the use case is essential to minimize setup time, encompassing aspects like colour schemes, rendering textures, transparency, and viewpoints (Preim, 2011). Thirdly, simplifying interaction through widgets or similar tools, such as snapping functions or information augmentation, is crucial to enhance usability (Schmidt et al., 2008; Preim, B., 2011). Lastly, to effectively introduce innovation in medical practice, well-defined and minimally disruptive workflows, graphs, or networks should be integrated, subject to rigorous analysis, evaluation, and optimization to ensure smooth adoption and seamless integration into existing practices (Preim, B., 2011).

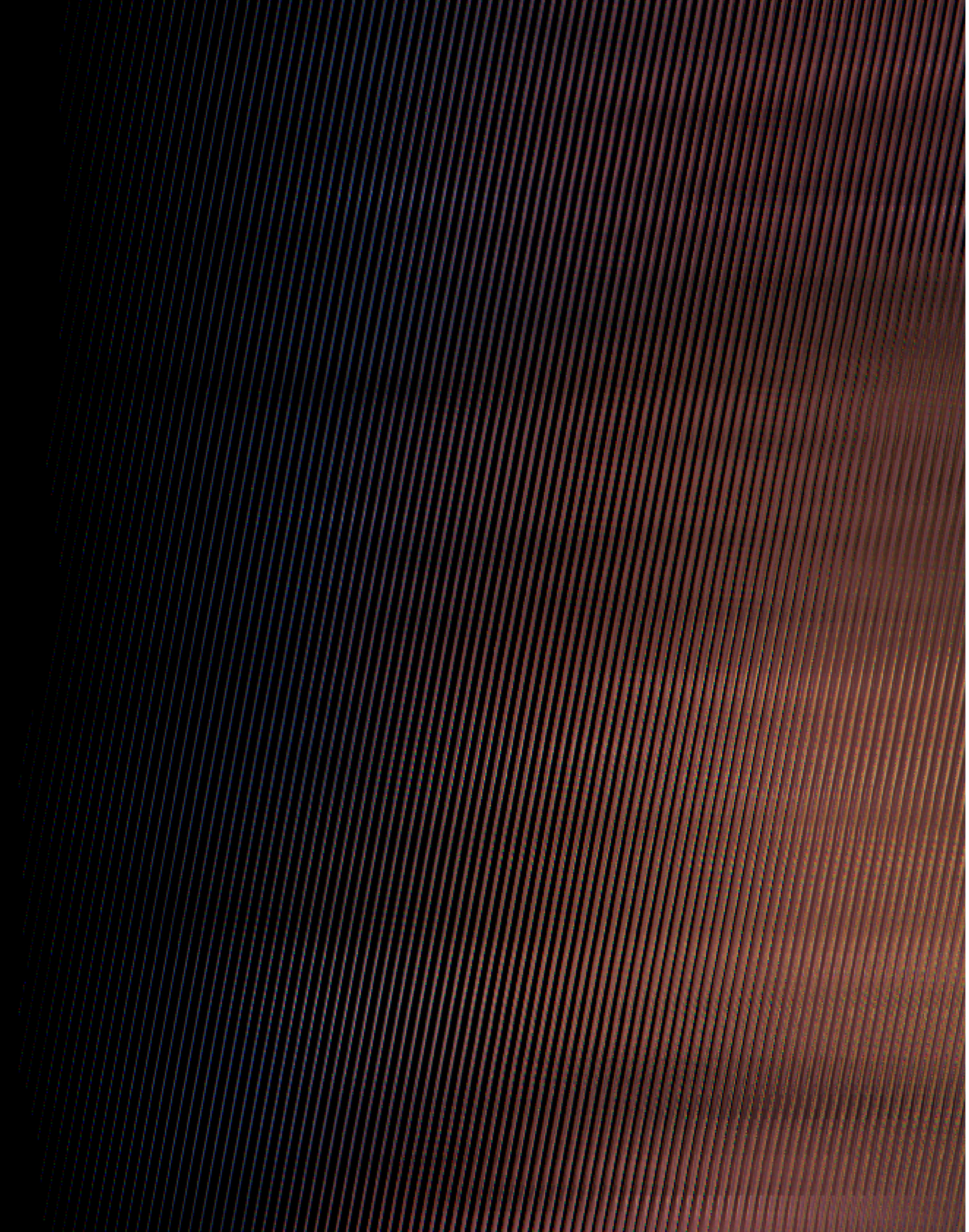
In summary, the design of medical visualizations must consider minimising disruption, time investment, and risks related to the introduction of new technology and associated interactions.

Innovation in healthcare

Notably, the considerations outlined in the previous paragraph align with the fundamental values of healthcare organizations, such as „quality, safety, efficiency", as identified by Omachonu and Einspruch (2010). These values are intertwined with the overarching challenges of innovation within the medical field, which must be taken into account when designing for medical practitioners. In short, the difficulty of changing clinician behaviour (Greco & Eisenberg, 1993) and implementing healthcare innovations (Shortell et al., 2001) are challenged by clinician resistance (Huntington et al., 2000), regulatory constraints, and high stakes in healthcare, all of which can impede the adoption of innovation (Omachonu & Einspruch, 2010).

// Need for expanding the literature scope

The review of medical literature revealed a significant gap in design insights and techniques related to 3D interaction, manipulation, and navigation environments. While there is a multitude of adjacent literature, there is a striking lack of emphasis on interaction from a human-centred perspective, with even fewer resources dedicated to the design of navigation systems. This might be connected to the scarcity of summative evaluations in medical visualization (Preim, 2011), which could explain why only a limited number of techniques have been reported. Consequently, the scope of this literature review had to be expanded beyond the specific medical context's keywords to identify useful insights applicable to the design.



CHAPTER 04

INTERACTION TECHNIQUES

This chapter reviews 3D navigation and manipulation techniques outside the medical context considered applicable to the context and useful for the design in the scope of this thesis.

Interaction Techniques from non-Medical Literature

// Techniques for navigating 3D

In the realm of 3D interactions, this thesis primarily focuses on navigation techniques but acknowledges other valuable methods related to manipulating 3D models and controlling systems through UI elements.

One noteworthy technique, Speed-coupled Flying with Orbiting (Tan et al., 2001), offers a seamless transition between a fast, free bird's-eye view navigation and a more controlled detailed object inspection within a 3D environment (Figure 6). Users can navigate fast and freely in the overview mode by dragging the mouse, they then can descend smoothly towards an object of interest. Once this is selected, the object remains at the centre of the viewpoint while allowing horizontal orbiting around it (controlled by left/right mouse movements) and vertical movements for zooming in/out. This type of navigation is relevant for the context because surgeons need to visualise both the overview of the 3D model for patient-specific anatomy, as well as precise landmarks and its close surroundings.

In addition to navigation techniques, Jankowski & Hatchet (2015) introduce the concept of "specified trajectory movement", which involves following a predetermined path to provide a controlled experience. This movement serves various purposes, such as showing important objects, optimizing views based on context, and preventing user disorientation.

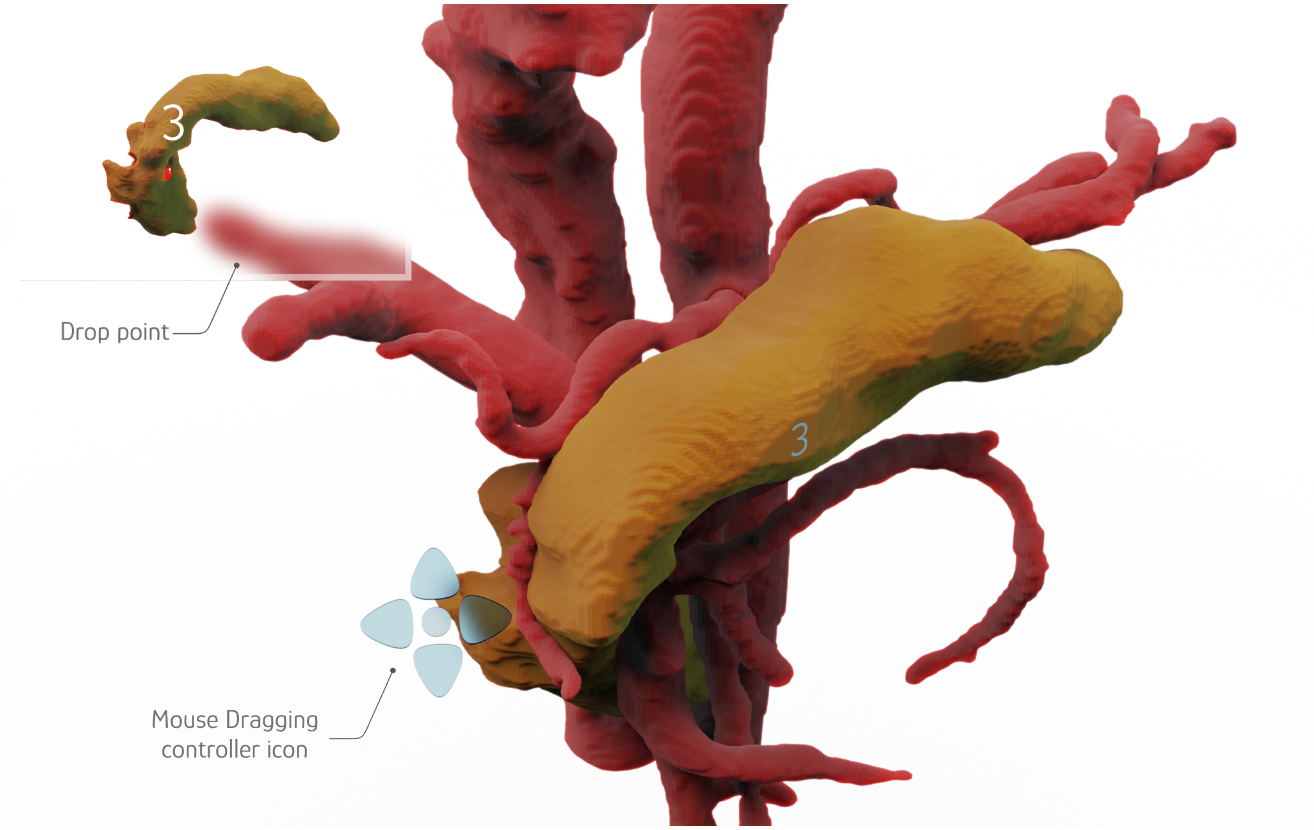


Figure 6. Speed-coupled Flying with Orbiting (Tan et al., 2001), applied to an example of inner abdominal anatomy as to contextualise in the medical domain.

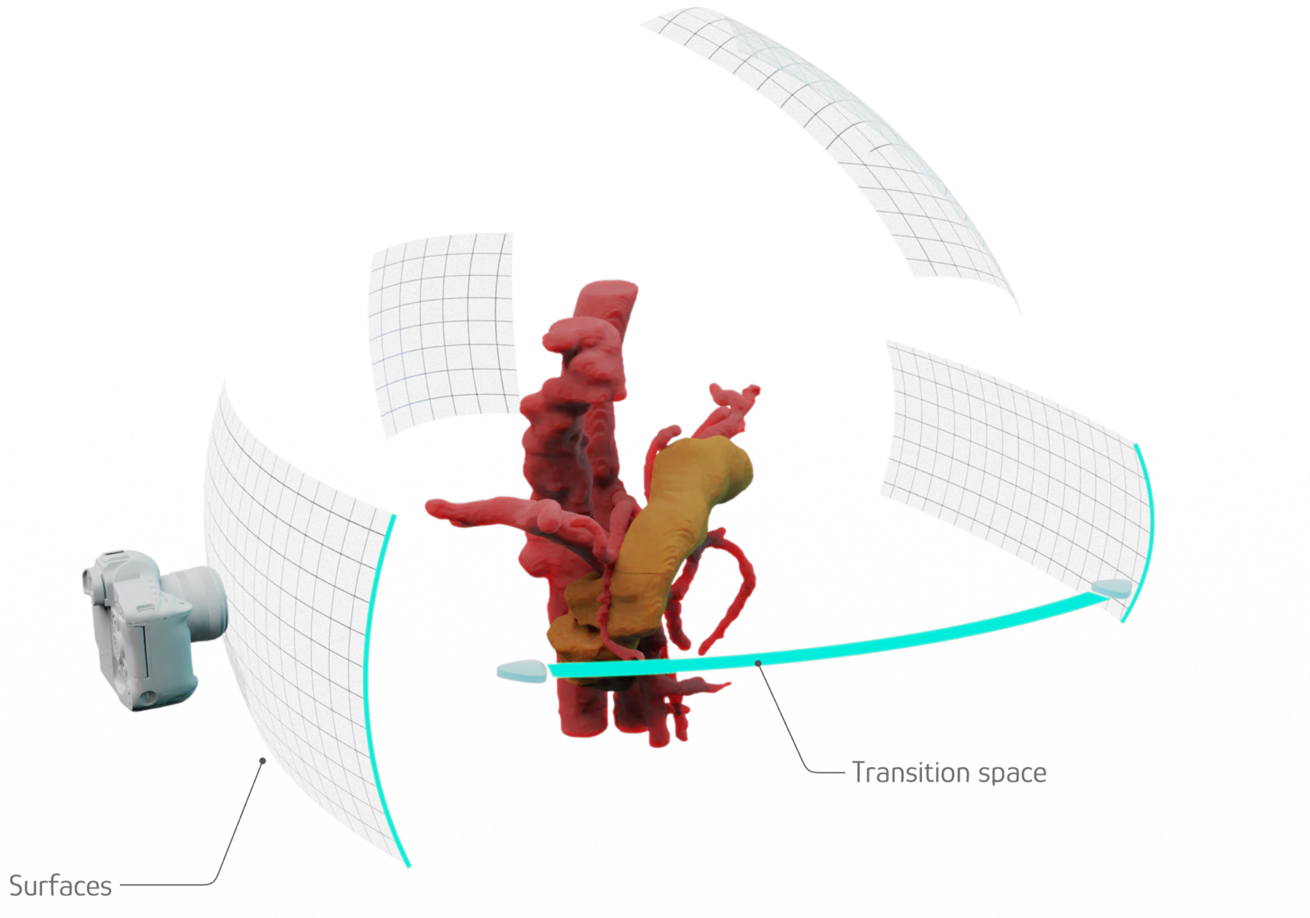


Figure 7. StyleCam system by Burtnyk et al. (2002), also here applied to the medical example of the hepatopancreatic-biliary region. The user has different levels of control, depending on which part of the flow they are.

Within this category, the StyleCam system by Burtnyk et al. (2002) stands out (Figure 7). StyleCam enhances navigation by combining spatial camera control with animation playback. It empowers authors to tailor the user's viewing experience in terms of content and timing using a states and transitions system. (Figure 7) This technique seamlessly shifts between high, mid-level, and no control, allowing users to switch between spatial and temporal control effortlessly. StyleCam's ability to balance control throughout the experience is noteworthy, as it ensures a satisfying user interaction while avoiding potential frustration due to inappropriate control levels at different stages. Such flexibility aligns with the needs of medical experts when examining 3D anatomy because it allows them to efficiently concentrate on crucial aspects of the model without investing time in less relevant sections.

In 3D navigation systems, the integration of different levels of detail is often essential. The concept of Overview-plus-Detail (Jankowski & Hachet, 2015) interface design, or Mini-maps, which was employed in different research approaches (Baudisch et al., 2002; Cockburn et al., 2009), has gained popularity, particularly in video game interfaces. Chittaro and Venkataraman (2006) explore the use of 2D maps as a navigation aid in multi-floor virtual buildings, a concept relevant to the relationship between CT scan slices used to construct 3D models. This applies to the Integrated Imaging Workstation as well, because it deals with a 2D and a corresponding 3D visualisation.

Widgets are a flexible way to facilitate navigation. Notably, 3D arrows are employed to guide users to points of interest within the virtual environment (Chittaro & Burigat, 2004, 2007). Another established approach involves the use of ViewCube (Khan et al., 2008), a graphical representation that aids users in understanding the orientation of 3D objects. (Figure 8)

Jankowsky & Hatchet (2015) highlight the leadership of the video game industry in 3D interaction development. They emphasise the importance of scalable UI concepts in terms of user skill levels, catering to both novices and experts. Most games implement the head-up display (HUD), a 2D interactive interface overlaying the 3D game world. Effective HUD design is characterized by its ability to enhance gameplay without disrupting the player's focus and experience (Rouse & Ogden, 2000), as seen in games like Far Cry 2 (Jankowski & Hachet, 2015), where the HUD adapts based on in-game context. Similarly, both scalability applies to surgeons with different levels of experience and the need to minimise disruption in their workflow (Preim, 2011).

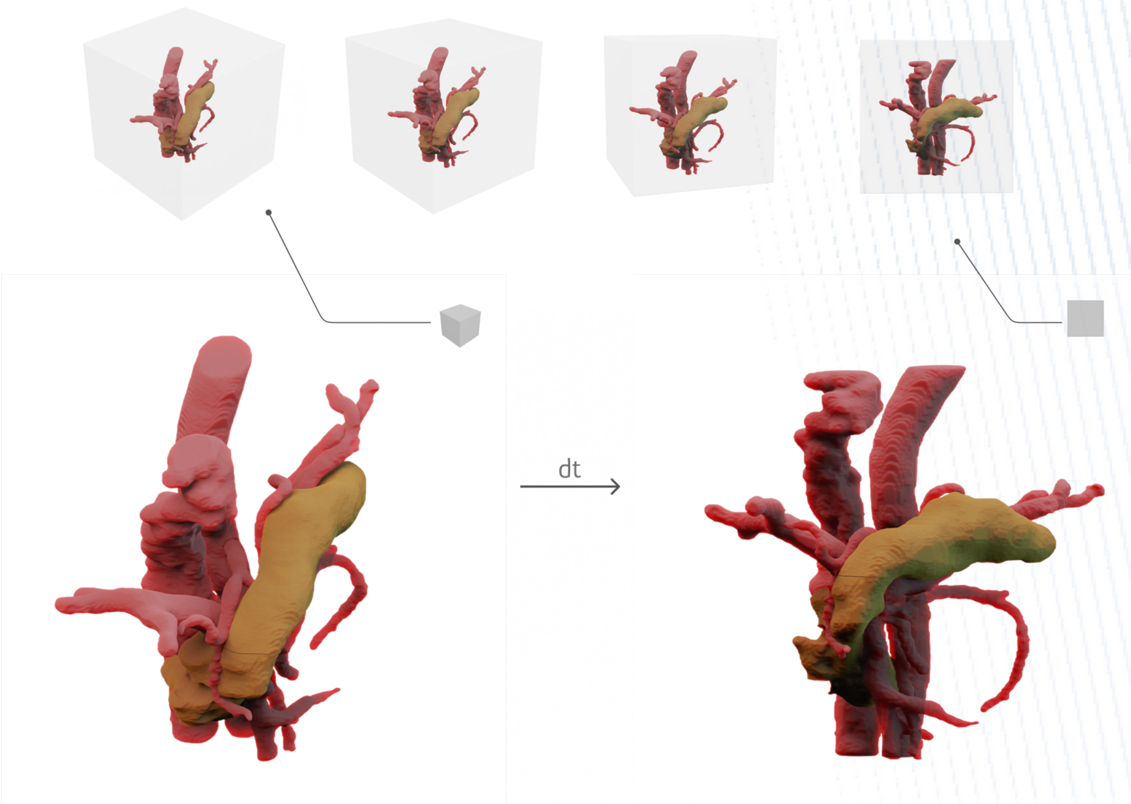


Figure 8. Example of a widget, using a medical example.

// Challenges of 3D Navigation

Designing interactions for 3D systems presents several key challenges, often stemming from poorly designed UIs and inappropriate interaction techniques (Jankowski & Hachet, 2015).
Building spatial knowledge and wayfinding (getting from one point to the other) is difficult in complex 3D environments, so designers have to focus on developing methodologies to facilitate navigation (Jankowski & Hachet, 2015) with constraints to support the user (Bowman et al., 2001), while still affording enough control to the user (Jankowski & Hachet, 2015): reaching this balance is crucial for designing a successful system. Addressing the occlusion of 3D objects is another common obstacle, often mitigated by using transparency (Elmqvist et al., 2007). Despite being not ideal for 3D manipulation, the Keyboard Mouse Input (KMI) system remains entrenched (Jankowski & Hatchet, 2015).

These challenges directly apply to the context of this thesis, where surgeons must efficiently inspect complex 3D anatomical structures within specific landmarks while considering the trade-off between control and speed. Additionally, addressing the entanglement of pancreatic tumours with branching vessels raises questions about what information to display when the camera approaches these critical areas.

CHAPTER 05

EXPLORATIONS

In this section, the main explorations and insights that contributed to gaining an in-depth knowledge of the daily context of hepatopancreatic-biliary surgeons and how they interact with medical imaging are presented. A questionnaire was prepared and dispatched to the Dutch Pancreatic Cancer Group (DPCG) to gain deeper insights into personal surgeon approaches to surgical planning, and two expert interviews were carried out. An in-the-field observation can be found in Confidential Appendix B.

Explorations: Diving into the surgeons' context

// Questionnaire - Understanding how surgeons use medical imaging

Aiming to enrich the understanding of the context and workflow of surgeons, an online questionnaire was devised and sent to volunteers outside of the inner circle of medical practitioners from the Catharina Hospital. Particular focus was given to unravelling which anatomical landmarks they prioritise, how they approach finding them on a CT scan and how they build an understanding of the patient's anatomy.

The main goal of this questionnaire was to gain insights into how different surgeons look at CT scans and work with DICOM viewers, including the self-perceived amount of time spent on the task, which information they annotate, the landmarks they searched for, and the way they looked at the medical imaging and the sequence of their examination process. The hope was to individuate personal preferences or patterns to take into account in the design phase.

The choice for a questionnaire was influenced by the scarce availability of surgeons for other arguably more suitable types of inquiry such as task-analysis (Crystal & Ellington, 2004). The advantage of this approach was that a broader audience could be reached in a shorter amount of time and it required a lesser investment from the medical practitioner.

The questionnaire was emailed to the closed mailing list of the Dutch Pancreatic Cancer Group (DPCG, https://dpcg.nl/) with a call for voluntary help. This association comprises medical practitioners such as surgeons, radiologists, oncologists and gastroenterologists specialised in pancreatic cancer throughout the Netherlands. The questionnaire was explicitly aimed at surgeons, and 12 valued members of the DCPG from different medical centres participated anonymously in the time window of approximately one month.

Before sending it, the questionnaire underwent different rounds of feedback with an experienced surgeon from CZE, for the questions to best fit the medical context and to ensure correct terminology for an unambiguous understanding of the volunteers. The design of the questionnaire was unconventional as it combined quantitative questions with Likert scales and qualitative, open questions connected to the context, with an emphasis on the latter. To help the participants evoke the moment of engaging with medical imaging (Sanders & Stappers, 2012), a picture of a DICOM viewer overlaid with a description of the context was provided (see Figure 9). The two most crucial moments in the surgeon's workflow of pancreatic cancer carepath were chosen to delve into: the first diagnosis of the patient's case and the preparation for surgery (nota bene, "preparation" in the context of this thesis is used interchangeably with "planning"). The same set of questions (Figure 10) was asked for both of these scenarios to understand if the surgeon's approach differed, and in what capacity.

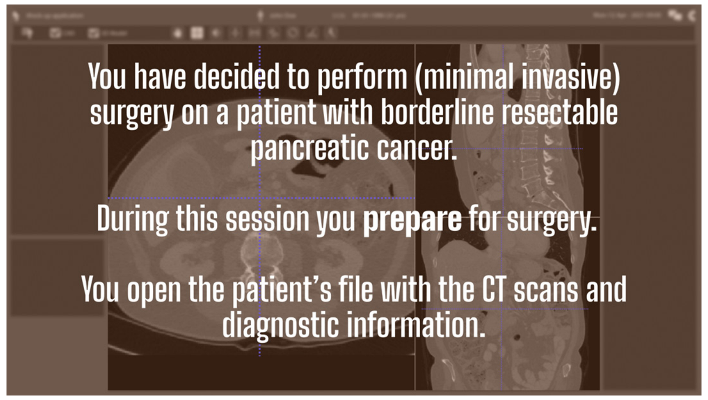


Figure 9. The introductory page of the questionnaire, with a contextualising sentence and a DICOM viewer on the background to bring the surgeons back to the moment preparation for surgery.

Questions	{First diagnosis phase / Preparation for surgery phase}
Q1	Approximately, how many times do you look at a patient's CT scan before {having a diagnosis / surgery}?
Q2	Approximately, how much time do you typically need to {diagnose the patient / prepare yourself for a complex surgery} using CT scans (in minutes)?
Q3	How well do you remember patient-specific anatomy before the {diagnosis / preparation}?
Q4a	If you write down any notes for your {diagnosis / preparation}, where do you annotate them?
Q4b	If you chose other, please specify here:
Q5	If you don't use annotations, how do you memorise relevant information?
Q6	What relevant information do you usually write on these notes, or memorise?
Q7	Besides tumour-vessel contact and ingrowth, which anatomical landmarks do you look for on the CT scan to find relevant patient-specific anatomy?
Q8	What is your personal approach to finding these relevant patient-specific anatomy using CT scans? (Describe in a timeline)
Q9	How often do you identify all the important patient-specific anatomy {in the diagnosis phase / before surgery}?
Q10	What are the most common problems occurring during {diagnosis / preoperative preparation}? What changes in your workflow would you make to improve this?

Figure 10.The complete list of the questions from the online questionnaire.

Questionnaire Results

The questionnaire was anonymously answered by 12 different expert surgeons (P1, P2,..., P12), from whom 7 reached the end of it. The others stopped at different questions, possibly because of the length of the form and the short time available to fill it up: indeed the median time spent on the questionnaire was 9 ½ minutes. The full statistics can be found in Confidential Appendix B.

Context understanding

Before reaching a diagnosis, most surgeons looked at the medical imaging once or twice. For those who answered the preparation phase, 75% of participants needed more looks at the imaging: mostly 2 or 5 times (Q1, Confidential Appendix B). A similar yet weaker trend was observed with the time they invested in the imaging: during diagnosis, the median amounted to 5 minutes, while for the preparation of the respondents, it rose to 10 (Q2, Confidential Appendix B). Similarly, regarding how well surgeons remembered the patient's specific anatomy, the preparation phase tendentially scored higher (Q3, Confidential Appendix B).

Regarding note-taking, the vast majority of participants (75%) used digital devices in both phases (Glossary G). In the diagnosis phase (Q4, Confidential Appendix B). The large majority of the surgeons noted anatomical variations and vascular involvement for both phases, with participants P4 and P5 mentioning a visualisation task such as "drawing a detailed overview" and "creating a complete 3D segmentation" for surgical planning (Q6, Confidential Appendix B). Those who didn't use annotations memorised the important landmarks. (Q5, Confidential Appendix B).

Regarding the frequency with which surgeons identify the important landmarks, more than half of surgeons chose the "99%" in both diagnosis and preparation. The other respondents started lower on the Likert scale and ended with a high response as well (Q9, Confidential Appendix B).

Personal Approach

The very same anatomical landmarks that the surgeons prioritised looking for in both phases were: Celiac Artery (or Celiac Trunk), Superior Mesenteric Artery (SMA), Superior Mesenteric Vein (SMV), Inferior Mesenteric Vein (IMV), Hepatic Portal Vein (HPV), Splenic Vein, Common Hepatic Artery, aberrant Hepatic Arteries (aRHA or aLHA). Landmarks that gained importance in preparations were the common Bile Duct, Gastroduodenal Artery (GDA), and First Jejunal branch (anterior or posterior to SMA). Various other landmarks were mentioned in diagnosis, preparation, or both (Q7, Confidential Appendix B).

Regarding the personal approach to finding the landmarks, no difference was found between diagnosis and preparation. Two groups of approaches were individuated (Figure 11; Q8, Confidential Appendix B):

1. The most common was the "Vertical Scan", where surgeons scrolled through the arterial and portal-venous phases interchangeably, moving vertically through the important anatomy.

2. The "Zoom In and Out" where participants started by localising the tumour and then expanding the inquiry concentrically towards other involved and critical structures.

The problems that most commonly occurred during diagnosis were to identify the primary tumour and different types of anatomic variations. During preparation, delineating the involvement of vessels was reported as the most challenging (Q10, Confidential Appendix B).

Contextual and workflow insights

The importance of surgical preparation (Q1 / Q2 / Q3)

Even though surgeons remembered the patient's specific anatomy better, surgical preparation required comparatively a higher time investment and consultations of the CT scans. This underscores the weight of preparation in the pancreatic cancer clinical workflow, which has to be taken into account with the design.

The need for visualisation during preparation (Q4 / Q5 / Q6)

Surgeons, when taking notes, preferred digital means, and mainly annotated anatomical variants and vascular involvement. During preparation, some of them changed from writing verbal notes to visualising with drawings or 3D segmentations. This might be a hint for a higher need for visualisation and the importance of gaining an overview for this phase.

Crucial landmarks for workflow (Q7)

The comprehensive list shows that there's a multitude of landmarks that surgeons looked for, but that a good part of the crucial ones are segmented for the IIW. Still, comparing the list of landmarks with the ones of the IIW, 4 important ones are missing: SMV, Hepatic Artery, Bile Duct and the first Jejunal Branch. These, and arguably the ones that were mentioned once need to be considered in the future development of the prototype.

How surgeons look at scans (Q8)

The two deduced types of approaches should be accommodated in the design of the improved 3D navigation system: this means that vertical scanning of the 3D model and

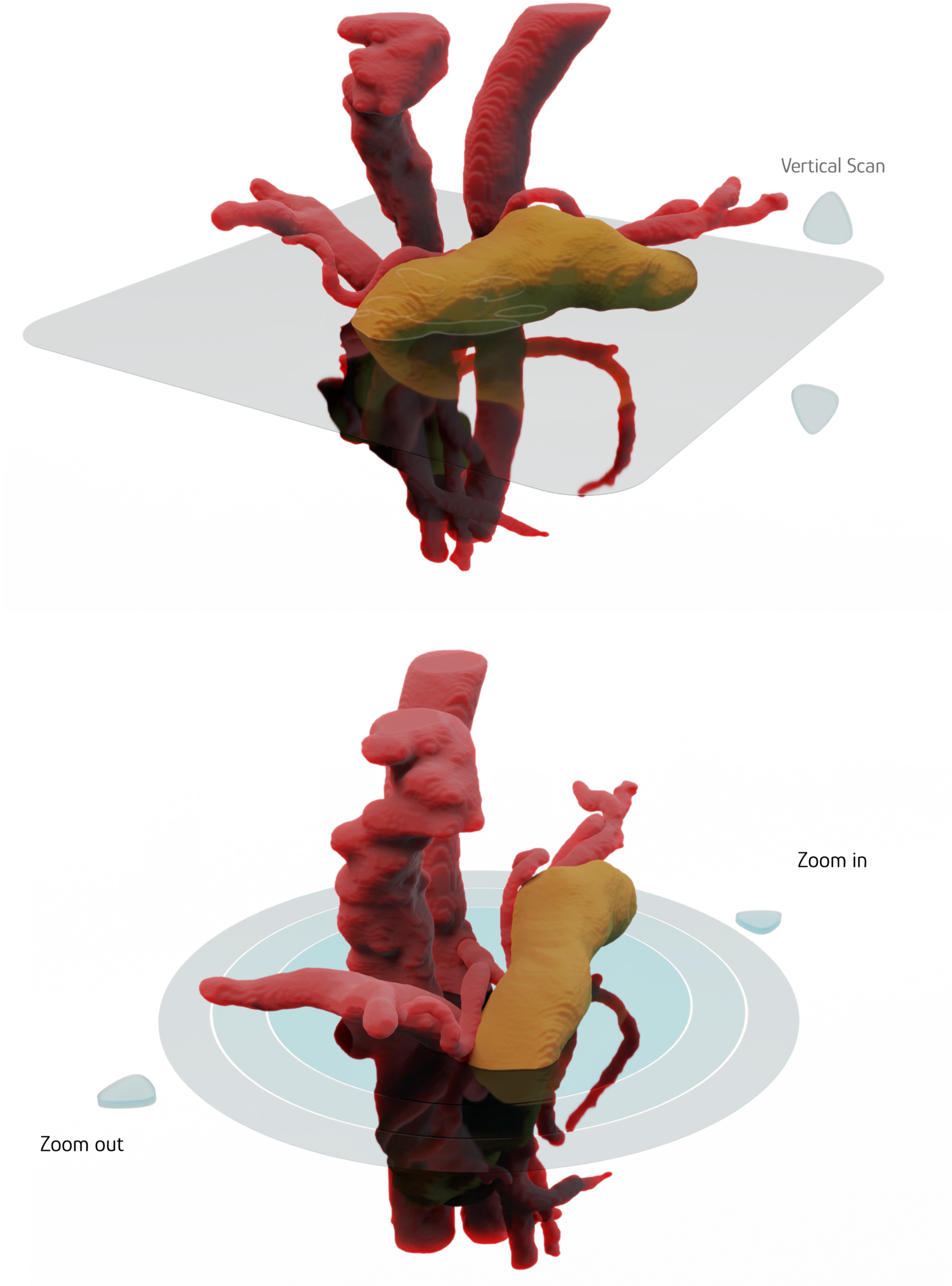


Figure 11.The two approaches that surgeons use to find crucial anatomical landmarks on a CT-scan, "Vertical Scan", and "Zoom In and Out". In these illustrations, the CT-scan information is represented in 3D.

concentrically zooming out from the tumour to inspect the interesting vessels should be viable interactions in the concept (Figure 11).

Small error margins (Q9)

Considering that most of the surgeons identify these landmarks - but also invest a lot of time in it (Q1/Q2), the design should probably focus on reducing the time needed to reach a decision and improve their confidence in the evaluation, instead of attempting to increase the quality of the clinical assessment (criteria from Preim, 2011)

Essential visualisation targets (Q10)

The answers from this questionnaire confirmed the direction of the project, as the anatomical variations and tumour-vessel involvement stand out as the main challenges in the clinical workflow. The design needs to emphasise these as main interest points.

// Expert interviews

As both the reviewed literature and questionnaire hint towards the importance of surgical planning but lacked a human-centred perspective, further steps towards this crucial part of the workflow were taken to understand their actions and interactions with medical imaging leading up to surgery. Two short (20-min long) interviews with the same expert member of e/MTIC who worked daily with the surgeons were recorded, transcribed and separately analysed with statement cards (Sanders & Stappers, 2012) and thematic mapping (Braun & Clarke, 2006).

Interview A: How do surgeons prepare a surgery?

The protocol and questions can be found in Confidential Appendix C.

The key insights provided by the interview supplement the clinical workflow from the introduction (Rasenberg, 2021). Surgeons iteratively build a mental representation of the patient's anatomy each time they engage with the imaging throughout the medical pathway: if a case is complex, the surgeons will have seen the scan enough to remember the anatomy. Once the decision for surgery is taken, surgeons prepare the case by themselves, usually a day or shortly before the operation.

The way the surgeons approach this preparation is by immersing themselves in the data (patient's case, notes from past MDT meetings) and thoroughly reviewing all available textual and visual information, challenging themselves to identify potential problem areas that could arise during the surgery, which are then memorised or noted down. Notably, the surgeon's preferences on how to look at the CT scan play a role in how cases are approached.

"I think it will also, these things will be surgeon dependent, I think. Because everyone will have kind of his own preference on how to look at cases."

These findings significantly influence their surgical approach. If grave doubts arise, they need to be probed right before surgery, for example with a biopsy (cutting a sample from the inner body and analysing it). The possible presence of anatomic variations leads to exercising extra caution when cutting through tissue to reach the pancreas, or conducting probes to verify their assumptions. Furthermore, the plan is constantly re-evaluated and updated based on the knowledge gained during the process. This means that the quality of the surgical preparation usually influences the need for intraoperative strategy changes.

Interview B: How do surgeons interact with medical imaging?

The protocol and questions can be found in Confidential Appendix D.

Findings from this interview partly overlap with those of the questionnaire: surgeons rely on CT scans to find anatomical interactions with tumours and build an understanding of patient-specific anatomical variations.
"For example, this vessel sometimes has an aberrant artery and then it goes like this to the liver (...) And I miss it and I cut it during surgery. We'll have a big problem."

The most important interactions with conventional DICOM viewers are zooming, panning, scrolling, and manipulating contrast. Less prevalent are the annotation and ruler tools, which are more oriented towards radiologists. Scrolling back and forth through different slices (z-axis of the scan) seems to enable experienced surgeons to mentally reconstruct a 3D representation of the patient's anatomy.

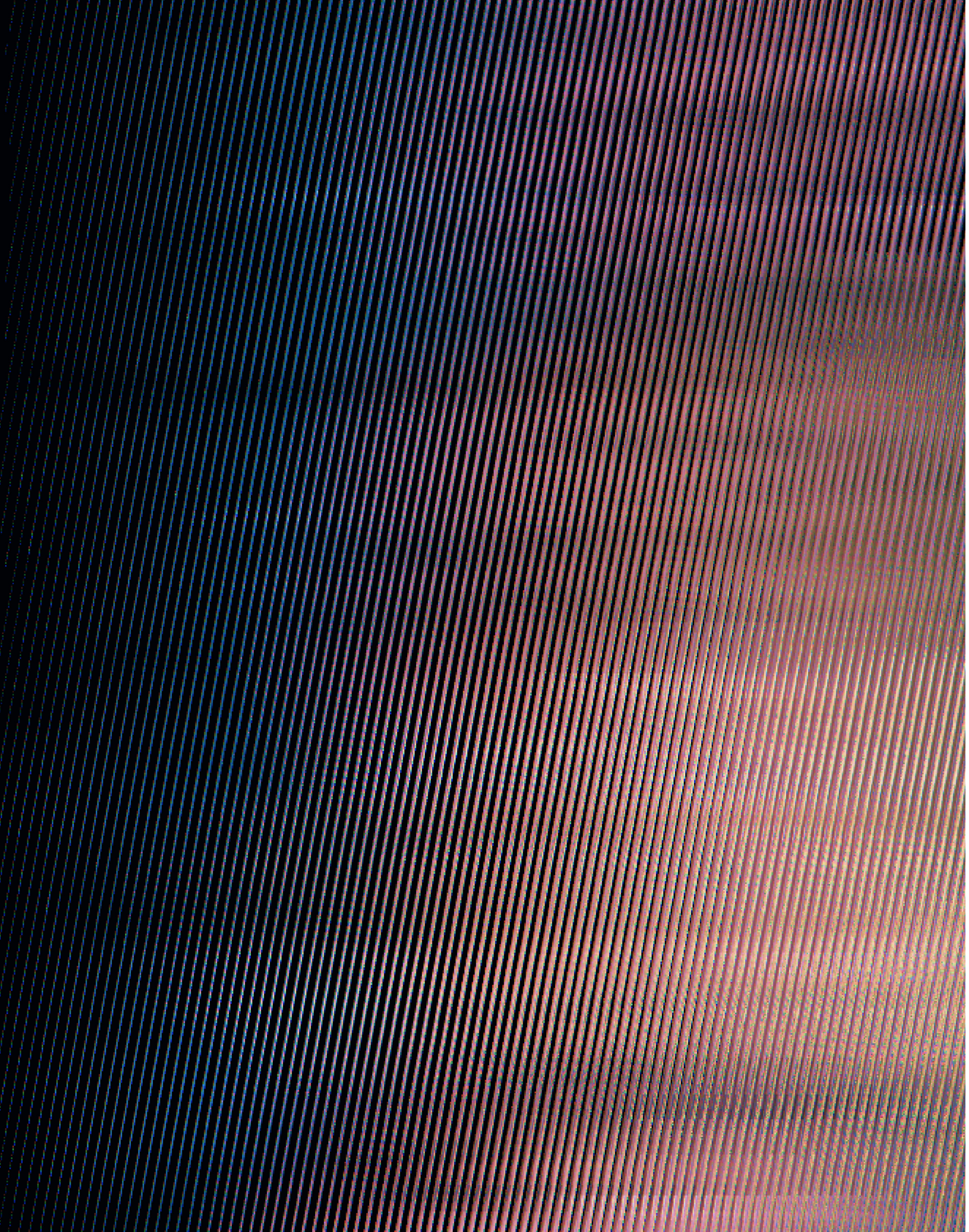
"Yeah, (the surgeon) always tells that when he looks at the CT scan, he knows in his mind how it will look like during surgery. He already reconstructs it in his mind. But he's a lot more experienced. So he will do that automatically. And also he's done hundreds of surgeries so he will know what it looks like during surgery."

Manipulating contrast also plays a pivotal role in visualising and identifying landmarks: arterial and portal venous are used interchangeably, and then adjusted back and forth with the DICOM viewer's contrast tool to find the best representation.

Insights from the interviews

The design of the navigation system needs to take into account that preparation requires multiple iterations of going through the crucial anatomical landmarks, possibly by facilitating this flow. It should ensure visualisation at the best contrast possible (which might translate as opacity for the 3D model), and considering the importance of scrolling, it shouldn't disrupt this interaction but rather accompany it on the autostereoscopic display.

A challenge is to design a system that can accommodate the variety of preferences that surgeons have in their approach, which could be approached with customisation or flexibility, for example.



CHAPTER 06

DESIGN OPPORTUNITIES

This chapter explores the insights gathered from both the literature and the practical explorations. It begins by addressing context-related research questions RQ1 and RQ2, and subsequently, it organizes and summarizes the insights into significant design opportunities.

From research insights to design opportunities

RQ1: How do surgeons use medical imaging for surgical planning?

Surgical planning or preparation typically occurs one day before the operation and requires more time and attention compared to the diagnosis phase. Surgeons engage in iterative reviews of medical imaging to identify potential surgical challenges. They utilize a DICOM viewer to zoom, pan, and manipulate image contrast for optimal visualization of landmarks on the scan. Importantly, they navigate through various slices of the scan, mentally reconstructing a 3D representation of the patient's anatomy. This workflow should be carefully considered in the design process, as the interactions involved are deeply ingrained in the surgeon's mental model.

RQ2: How do they approach finding anatomical landmarks and tumour-vascular interactions?

Surgeons exhibit diverse preferences and approaches in locating anatomical landmarks and tumour-vascular interactions, with a subset of key landmarks prioritised by all the participants, but also variations in their choices. Two approaches were identified: the „vertical scan", involving surgeons scrolling through arterial and portal-venous phases while moving vertically through critical anatomy, and the „zoom in and out" method, where they start by localizing the tumour and then expand their examination concentrically to encompass other critical structures. Preim's (2011) description of clinical tasks resonates with these, emphasizing the importance of following branching structures such as vessels and examining the surroundings of pathological structures. These findings offer a significant design opportunity to translate these approaches into 3D to enhance surgical planning support.

Visualising Overview and Detail

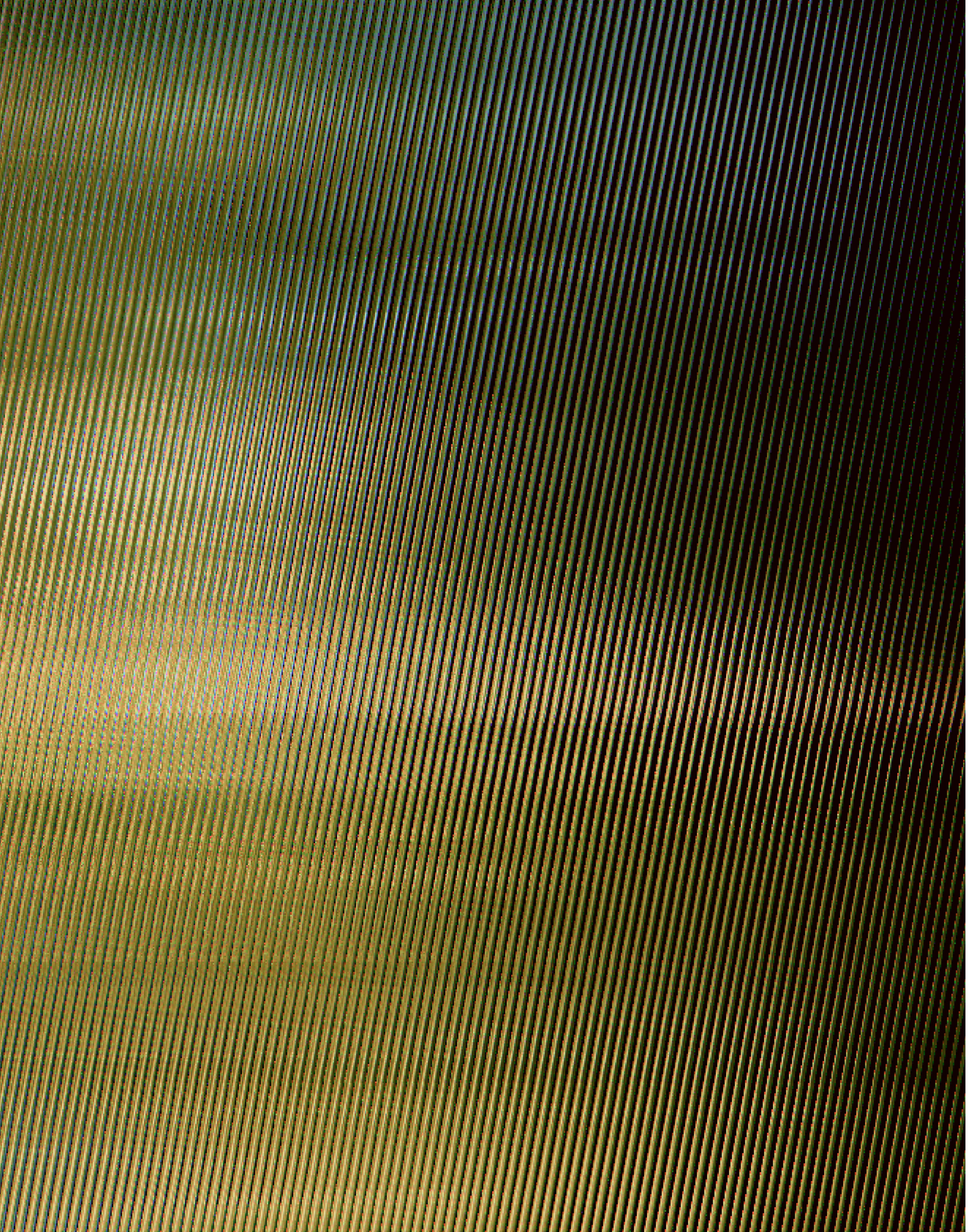
Surgeons lean towards visualising the overview of crucial patient-specific anatomy landmarks during surgical preparation, particularly in complex cases. At the same time, zooming into the model and seeing the interaction between anatomical and pathological structures is of great importance. Simultaneously inspecting overview and detail isn't desirable, as the amount of visual information visualised needs to be tailored to the object of investigation, to not clutter the surgeon's view. Basic camera movement and toggling elements on and off were used, as well as employing transparency to prevent occlusions were commonly used to tackle this, possibly not enough. The technique of Speed-coupled Flying with Orbiting appears promising for addressing these needs, enabling fast overview navigation with a smooth transition to orbiting around a landmark.

Minimising disruption

Implementing healthcare innovations and changing medical doctors' behaviour are complex tasks that require balancing improvements with the need to maintain quality, safety, and efficiency. It's crucial to minimize disruption, time investment, and risks while seamlessly integrating new technology. Preserving surgeons' existing workflow as much as possible is essential for a smooth transition. Therefore, this design must consider established interactions, such as scrolling, with 2-dimensional imaging during surgical planning and incorporate „vertical scan" and „zoom in and out". Additionally, leveraging interaction techniques from the video game industry, such as showing GUI only when needed, can prevent focus disruptions during the planning process.

Balancing speed and control in the interaction

Surgeons need to reach relevant visualizations quickly, highlighting the importance of simplifying interactions, such as utilizing default settings. At the same time, designing a fast navigation system requires adding constraints to support the user, thus reducing the control afforded. Therefore, designing a navigation system that provides the right balance of speed and control in the appropriate context is critical. The StyleCam is a promising technique because it allows customized control throughout the user experience. This could potentially allow medical experts to focus efficiently on critical landmarks within the 3D model, ultimately saving time that might otherwise be spent on less relevant sections.



CHAPTER 07

DESIGN

This chapter presents the key concepts, the main design direction, the feedback activities and the final design of this work.

Design

// Conceptualisation

Co-creation Session

During a one-hour brainstorming session at Philips involving five participants with diverse backgrounds, including a technical innovator, a medical technology expert, a psychologist, and a computer scientist, the aim was to explore innovative ways to integrate 3D technology into conventional medical scans beyond my personal ideation sessions. The session followed a creative facilitation protocol (Appendix E), starting with an icebreaker and then focusing on the main question: „How to connect 2D and 3D interfaces into one experience?" with brainstorming and clustering ideas. The morphological synthesis creative technique was used to generate novel concepts and solutions for seamlessly

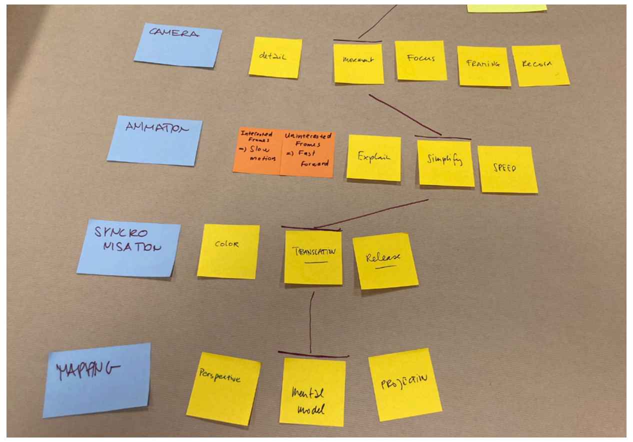


Figure 12. Morphological Synthesis activity, with the main themes on the blue postits deriving from the first brainstorm

merging 2D and 3D interfaces in the medical context. The brainstorming session produced promising results, with key themes including mapping and synchronization between 2D and 3D screens, guiding user focus with animations, and creating an interface where 3D extends from 2D. Noteworthy ideas included mapping the surgeon's CT scan slices to the 3D model, displaying 2D subsections in 3D, and synchronizing zoom levels. The use of animations to direct the surgeon's focus, resembling mini-maps and widgets, also emerged. These ideas offered valuable themes and inspiration for further brainstorming and subsequent conceptualization, which brought to the concepts presented next.

Key Concepts

CT scan as a 3D navigation interface

The core concept centers around enhancing the traditional DICOM viewer by introducing new features to facilitate interaction with 3D visualizations. Essentially, the viewer transforms into an interactive interface for controlling and navigating the 3D visualizations. The objectives encompass streamlining the learning curve associated with 3D model interaction through the use of a familiar interface, establishing a seamless connection between 2D and 3D visualization, and addressing the issues identified in the original Integrated Imaging Workstation, where surgeons often overlooked the 3D aspect of the prototype (Rasenberg, 2021). Additionally, the concept incorporates the idea of specified trajectory movement (Jankowski & Hachet, 2015) (Figure 13).

Synchronised Hovering

This concept entails enhancing the conventional DICOM viewer by introducing a hover feature. When the cursor hovers over a segment on the CT scan, both the segmentation and the corresponding full organ in 3D are highlighted, achieved by reducing the opacity of the other organs. This highlight serves as an invitation for further interaction, enabling users to click and explore the focused segment in greater detail, and it provides a means to map the segmentations on the 2D scan to the 3D model.

Focused Segment

Clicking on a specific segment brings the organ into the spotlight, providing a specific camera perspective in the 3D view optimized for thorough inspection by surgeons. To improve visibility, the surrounding organs are rendered less opaque, allowing surgeons to visualize potential intersections between organs. The autostereoscopic display enhances scene observation from various angles, adding depth to the view. Users can deselect by clicking on another segment or within a region without segments.

Snapping

To enhance user navigation and improve cursor awareness and orientation when dealing with small segments on the CT scan, a snapping feature has been implemented. As the user hovers the mouse over any segment, it automatically snaps to the center of the segment. This ensures precise interaction and assists users in efficiently accessing and navigating through the segments.

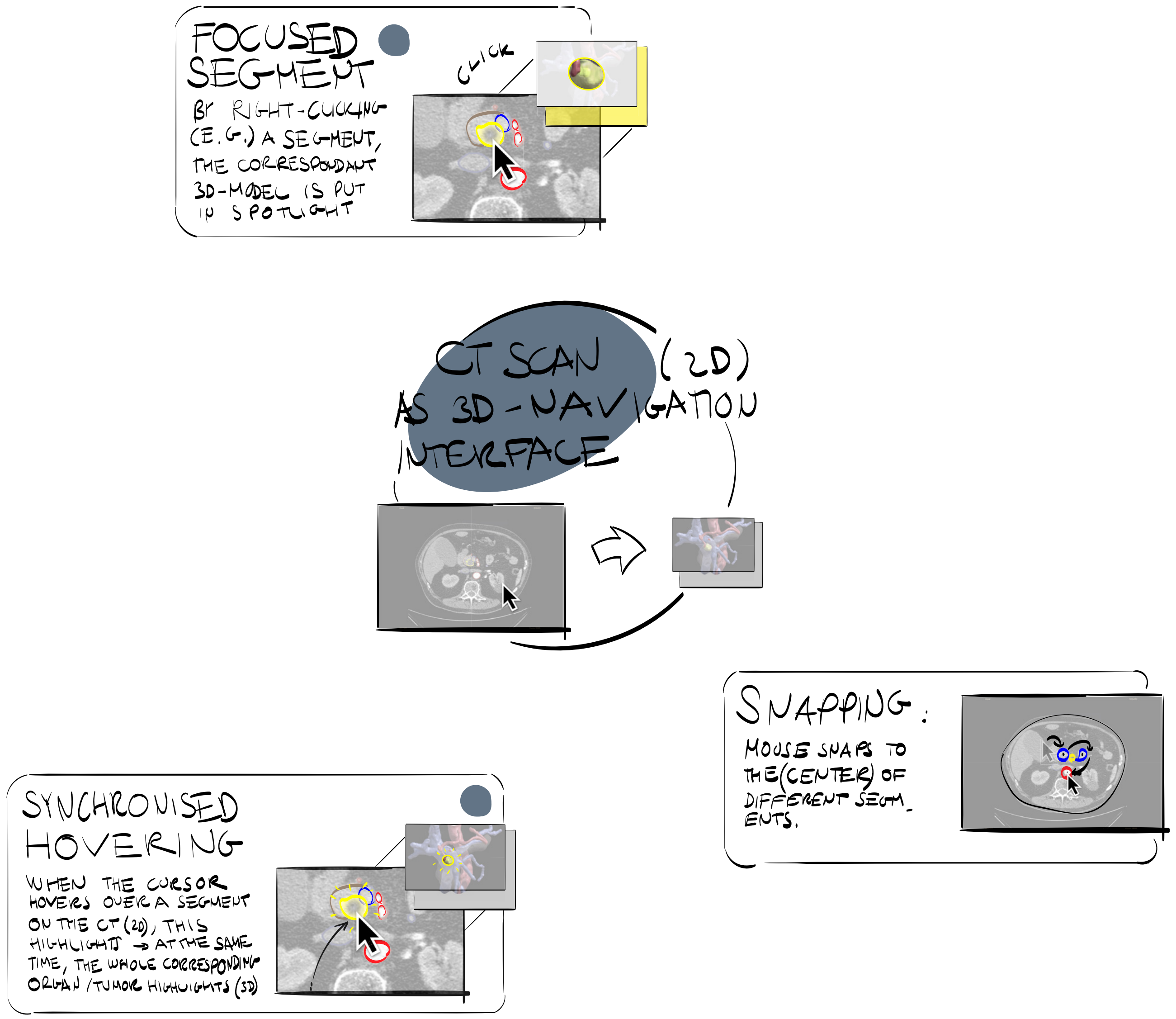


Figure 13. Key concepts revolving around „CT Scan as a 3D navigation interface"

Modal 3D Navigation

The central concept revolves around customizing the visualization and navigation of each organ type based on its unique characteristics, catering to surgeons' preferences for examinations. Users can seamlessly switch between different organs, allowing for specific navigation methods tailored to each organ or tissue type, ensuring an efficient workflow. In the figure 14, „Vessel mode" and „Tumour mode" represent distinct interactions for camera control within the navigation system. To strike a balance between meeting surgeons' inspection needs without overwhelming them or causing „lost-in-cyberspace" scenarios, this concept incorporates the notion of Specified Trajectory Movement (Jankowski & Hachet, 2015). It draws inspiration from the orbitation mode in Speed-Coupled Flying with Orbitation (Tan et al., 2001), enabling surgeons to mentally construct a model of the specific anatomy (Fitski et al., 2020; Kenngott et al., 2022; Marescaux et al., 1998). The overarching goal is to provide an intuitive and personalized navigation system that aligns with surgeons' visualization requirements, facilitating efficient and effective examinations of various organs (Figure 14).

Overview Mode

This camera position serves as a default view, enabling surgeons to orbit around the complete organ composition. This feature is invaluable for enhancing awareness of vessel branches and specific anatomy, aiding surgeons in constructing a mental model during their pre-procedure preparations (Figure 14.

Vessel Navigation

Here, the camera adopts a first-person point-of-view and navigates through the vessels, automatically focusing on tumor involvement when detected. Surgeons can also explore various branches, providing a comprehensive view of the organ's internal structure and following paths within elongated branching structures, as advocated by Preim (2011). Visualizing ingrowths and overlaps from within enhances clarity and promotes a deeper understanding of intricate details. (Figure 14)

Ingrowth Visualisation

In this conept, the camera revolves around the overlapping region, displaying the involved organs, vessels, and carcinoma with reduced opacity to provide a clearer view of their interactions. Surgeons have the option to use the zoom function for close examination of pertinent points (Figure 14).

Mode Jumps

Enables surgeons to seamlessly switch to a different model while navigating within a mode, facilitating rapid transitions to new specific modes. This functionality enhances flexibility and simplifies exploration, enabling surgeons to effortlessly shift between different models as they navigate through the system (Figure 14).

Mini-map

Inspired by common video game interfaces (Jankowski & Hachet, 2015), this concept utilizes the CT scan as a 3D visualization minimap. The minimap updates the selected slice and cursor position in real-time, seamlessly connecting the 2D and 3D views. It provides instant feedback on the 3D visualization to reinforce the connection between 2D and 3D representations and promote a shared mental model (Norman, 2013). The minimap aids surgeons in orienting themselves within the 3D environment, facilitating efficient navigation and preventing disorientation, as suggested by Jankowski and Hachet (2015) (Figure 14).

Other concepts

Additional concepts that explore various directions regarding interactions and focus can be found in Confidential Appendix F.

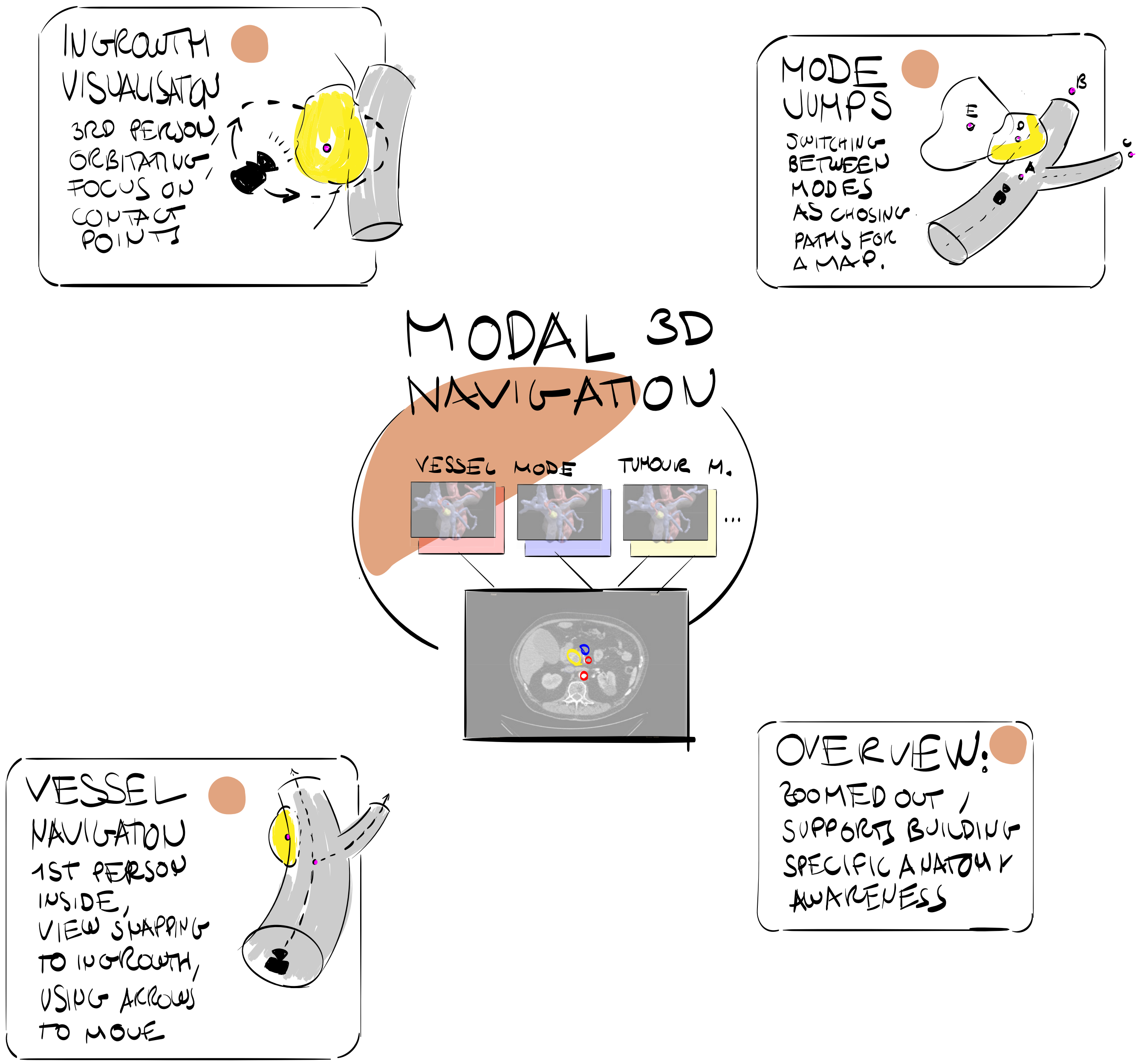


Figure 14. Modal 3D navigation, with the key conepts related to it.

// Design direction

Selection based on desirability

To determine which concepts were favored by medical experts and establish a specific design direction, a feedback session was conducted with an experienced individual at Catharina Hospital. In this session, printouts of the concept sketches were presented, and the participant identified the most suitable ones for the context of surgical planning for complex cases of pancreatic cancer. The feedback was recorded in audio and later transcribed for reference. Subsequently, the concepts were grouped into three categories based on their desirability, which will be briefly outlined here.

The interview with the expert surgeon revealed several potentially valuable concepts for enhancing the surgical visualization system (Figure 15). Notably, the preference for using the CT scan as an interface for 3D visualization due to its simplicity was highlighted, along with the value of the Focus fade-off concept in maintaining the integrity of the CT scan. The Mini-map concept received positive feedback for aiding orientation between 2D and 3D views, while ingrowth visualization concepts that focused on tumor areas and interactions with vessels were considered beneficial. However, certain concepts, such as navigating vessels from the inside or implementing mode jumps, were criticized as inefficient for surgeons' workflow. Overall, the importance of designing efficient and practical solutions that align with medical professionals' needs and constraints became evident, with preferences leaning towards concepts that balance speed and control, ultimately informing the main design direction.

Combining the promising concepts in one

Based on the feedback received on desirability, the final design direction was determined to focus on the integration of two key concepts: „CT scan as a 3D navigation system," particularly emphasizing the selection and hover functionalities, and „ingrowth visualization" combined with „overview," specifically for its orbiting feature around points of interest. This combined approach effectively addresses the surgeons' needs, encompassing the personalized approaches identified during the explorations. It allows for zooming in and out and conducting vertical scans through orbitation. Moreover, it aligns with the concept of minimal disruption since it leverages the CT scan as an interaction tool with the 3D, eliminating the necessity for direct interaction with the 3D model, which surgeons might not be accustomed to. „Ingrowth visualization" and „overview" cater to the requirements of zooming in for detailed segment investigation and visualizing the complete anatomy for patient-specific anatomical references. Selecting a segment on the scan will position the camera near the corresponding 3D model, and hovering over different segments will adjust their opacity for enhanced visualization. With this established design direction, the first prototype was implemented.

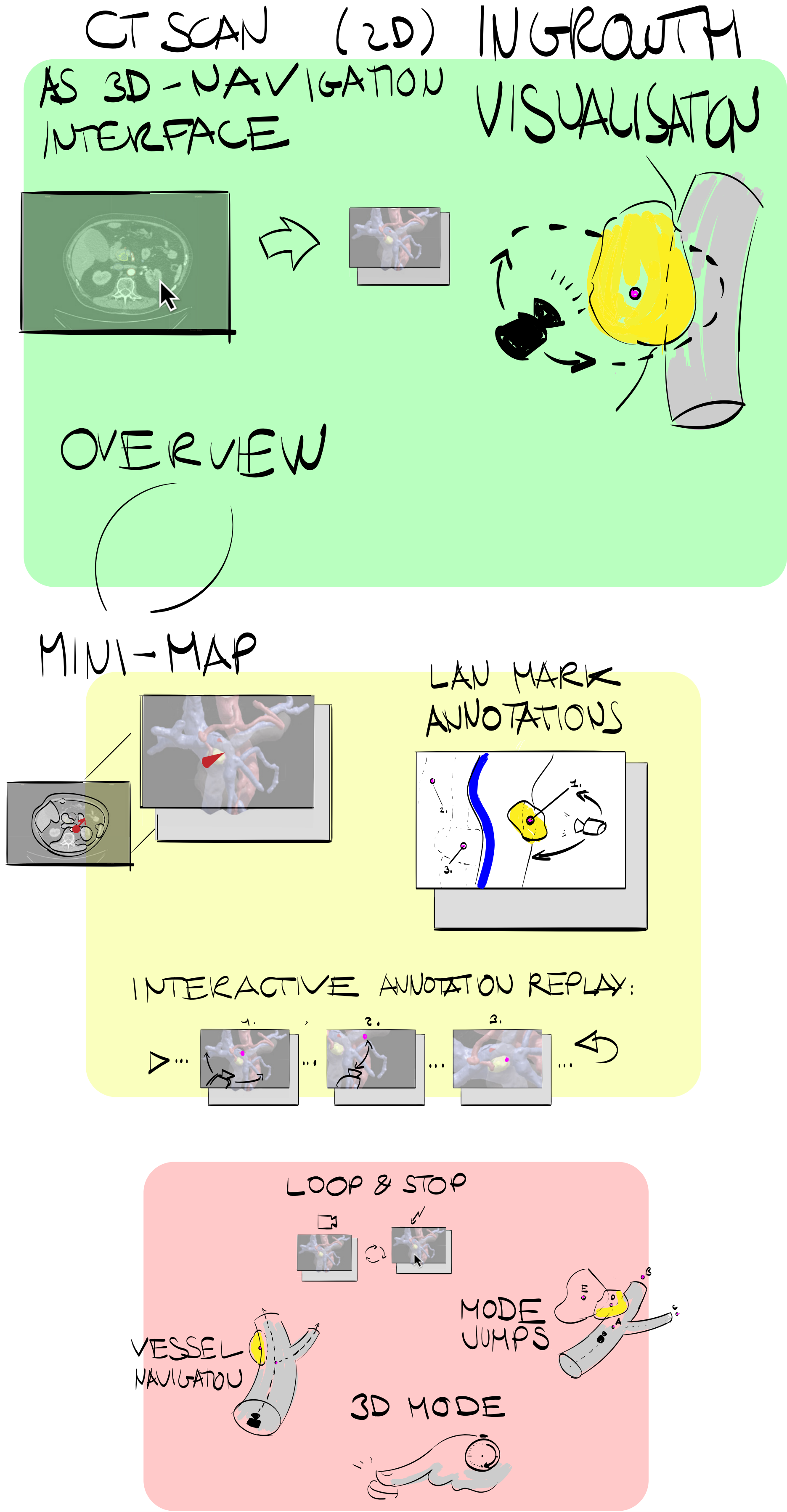


Figure 15.Three tiers of desirability. The concept chosen to combine for the design direction, were the „CT scan as a 3D navigation system," „Ingrowth visualisation", and the „overview"

// Refining the design

Preliminary feedback

Once the design direction was set, a first Once the design direction was set, a first iteration of the combined prototype with Unity3D and React was implemented. This preliminary version of the concept was then used as a probe to yield feedback from an expert HPB surgeon at the Catharina Hospital (Figure 16), following the research through design approach.

This 15-minute session aimed to preliminarily assess the "CT Scan prototype as a 3D navigation interface", specifically focusing on the "Focused Segment" and "Synchronized Hovering" concepts. The objectives were to assess the ease of interaction understanding, and surgeons' comprehension of the 2D-3D relationship, identify potential shortcomings, and gather feedback for refinement. The surgeon performed tasks involving „selecting the pancreas" and „exploring the DICOM viewer" while providing verbal feedback. Features not implemented yet were verbally explained. Questions explored interaction intuitiveness, perceptions of the prototype's integration of 3D into 2D, and interaction expectations when inspecting organs, along with workflow (protocol and questions in Confidential Appendix G). The interview was recorded, transcribed and thematically analysed.

Insights

The surgeon found the connection between 2D and 3D to be straightforward and favoured interacting through the CT scan rather than directly manipulating the 3D model. Regarding "Modal 3D navigation", he was satisfied with orbiting around the vessel or tumour-vessel interaction. The surgeon stressed the importance of starting the 3D visualization with the same orientation during surgery (with the pancreas frontal), aligning with the concept of „Default settings" (Preim, 2011) for a quick start. He also supported the idea of receiving guidance for orientation between 2D and 3D visualizations, including projecting the current slice onto the 3D model and synchronizing rotation between views.

The surgeon encountered usability issues with the "CT scan interface for 3D". He found it challenging to deselect a segment and return to the overview, as the method for doing so wasn't intuitive and required verbal guidance. Additionally, when clicking on a segment, he expected it to toggle the corresponding 3D model on or off and preferred visualizing holograms in different combinations rather than having the organ selected from an arbitrary viewpoint. While he didn't see the highlight of 3D holograms as particularly useful for identifying organs, he appreciated its utility for controlling opacity.

"I would think intuitively when I click on the organ, it would disappear or it appears not really highlighting it. I think every surgeon knows there's a pancreas. "

Minor insights revealed that the surgeon considered a limited zoom level sufficient for tumour visualization, valued the overview camera for anatomy location, commended the fast camera movement during the interaction, and acknowledged the potential of 3D for training purposes.

Figure 16. The feedback session with the surgeon, at the CZE. The surgeon expressing the need to turn the model.

Design Updates

A critical selection of the insights was selected to round up the overall usability and experience for the final implementation of the navigation system:

1. Implement the orbitation interaction (with dolly in and out)
2. Update the behaviour of selecting and hovering over segments for a more intuitive and useful interaction
3. Set the starting orientation of the hologram from a supine perspective for a faster start
4. Map slice position in 3D for better orientation

// Final Design: A Surgeon-Friendly 3D Navigation System

Figure 17. The final design setup, autostereoscopic display, and interactable DICOM viewer

// Overview

The final design combines three concepts, namely, „CT scan as a 3D navigation interface" and „ingrowth visualisation" in a refined version following feedback from the surgeon. It involves a conventional DICOM viewer augmented to allow direct interaction with various anatomical landmarks and tumors represented on the scan using AI-generated segmentations. This integration is complemented by the autostereoscopic display, building upon the existing 3D prototype. The interaction system includes multiple cameras that can be moved and allows adjusting opacity for the 3D model, even enabling elements to be turned off. Importantly, both components are synchronized and represent the same medical data.

Interactable CT scan

This concept enhances the conventional DICOM viewer with AI-generated segments that can be selected and hovered over (Figure 18). When at least one segment is selected, only the corresponding 3D elements are displayed on the 3D side. Selection actions include the option to turn elements on/off and enter orbiting mode, depending on whether it's a tumor, organ, or main vessel trunk, with priority given to the higher-priority view (e.g., tumor). Hovering, while at least one segment is selected, temporarily reveals a 3D vessel with reduced opacity.

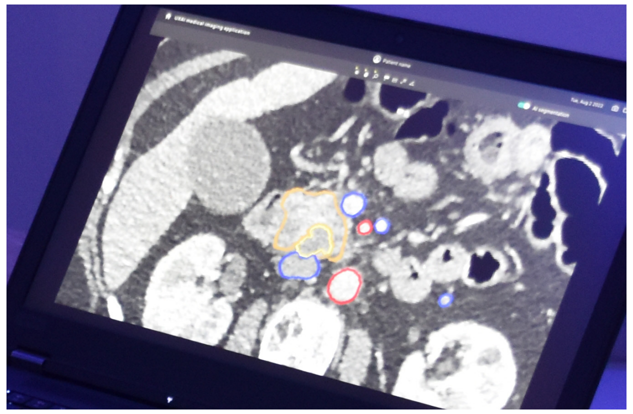


Figure 18. The medical imaging, that can be interacted with by hovering or selecting one or more of the colored segments - which triggers change in opacity and movement of camera in 3D.

Orbitation around the selected 3D landmarks

When an anatomical landmark is selected, its corresponding 3D version is positioned at the center of the camera's view, allowing the surgeon to control the camera's orbiting trajectory (Figure 19). Multiple elements can be selected, each triggering different points of view, but all crucial points remain centered in the camera's view. To control the rotation around the landmark, the WASD keys are used for moving up, down, left, or right, while RF keys are used for moving the camera closer to or farther away from the object. These movements affect the respective camera in the 3D space. Importantly, the cameras retain their positions, enabling surgeons to resume their inspection from where they left off.

Figure 19. The model can be orbited around with keyboard input.

Different cameras

The default camera, known as the overview camera, displays all the organs with high opacity from a perspective resembling a surgeon operating on a supine patient. In the overview camera, all 3D elements are visible. When switching to another camera through selection, only the chosen segments are displayed along with their respective turned-on organs in the 3D view, offering the flexibility to toggle segments on or off. The camera system comprises an overview camera, individual cameras for tumors, veins, arteries, and each segmented organ, as depicted in the picture. Each of these cameras is activated when selected as the first camera, except for the tumor camera, due to the camera selection's state logic, which incorporates an inherent priority system. Additionally, these cameras start in proximity to the organ of interest, as indicated in the Figure 20.

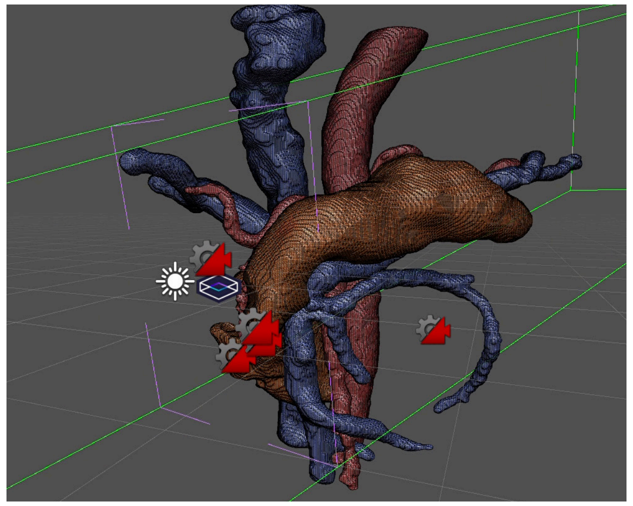


Figure 20. The red icons represent the cameras of the system, visualised from the Unity3D editor.

Navigation flow

To investigate tumor-vessel interactions in the 3D model, the surgeon selects the tumor on the CT scan, which brings the 3D camera close and conceals all other holographic vessels. Subsequently, the surgeon can activate other vessels that may be affected and use keyboard controls to rotate around the tumor, examining potential points of vessel intersection (Figure 21).

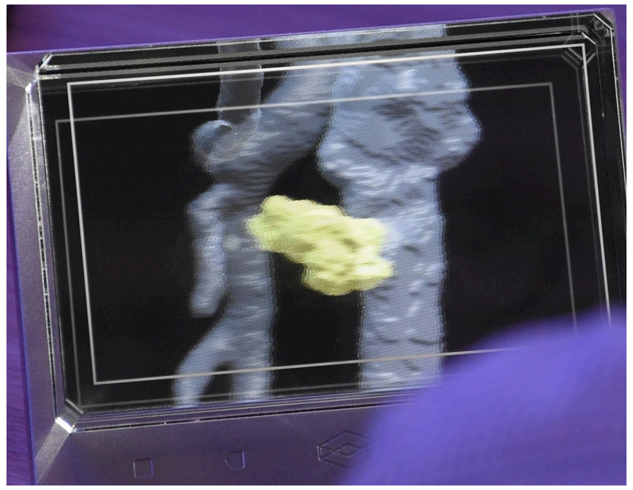


Figure 21. Tumour in yellow, and two veins, where there could be some ingrowth.

For identifying patient-specific anatomy, the surgeon initially employs keyboard commands to rotate the overview camera, displaying the entire anatomy on the autostereoscopic display. If they wish to delve deeper into a vessel and its branches, they select the desired vessel and branches on the CT scan (Figure 22). This action triggers the camera to switch to the nearest one, displaying only the selected parts. They can then use keyboard controls to orbit around the model for visualization.

Returning to the overview camera (Figure 19) requires deselecting all the chosen segments. If the surgeon wishes to visualize a landmark again, the cameras corresponding to that landmark will remain in their previous positions.

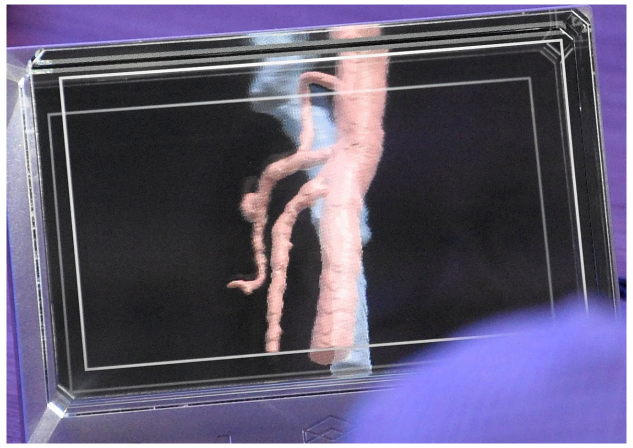


Figure 22. Inspecting patient-specifica anatomy, looking for potential anomalous branches.

// Implementation

Overview

The implementation phase spanned the project's design stage and involved typical software engineering tasks. This included code analysis, scalability improvements, and debugging. In the React web application, SVG segments were generated from expert segmentations, enabling interaction through JSON messages sent via a local websocket. Unity's 3D model implementation was overhauled using an object-oriented approach, featuring various managers:

- Websocket Manager: Handles communication.
- 3D Model Manager: Manages the 3D model, including opacity.
- Camera Manager: Controls different cameras.
- Interaction Logic Manager: Manages user interaction.
- Camera Transition Manager: Handles camera transitions using an animator state system.
- User Input Manager: Enables user-controlled camera orbitation.

Custom scripts were added to enhance scalability for future use.

Message exchange example

This is how the websocket message handling works: When a message arrives via the websocket, it's processed by the websocket manager, which then sends an event trigger (Figure 24) message to all the listening classes. For instance, if a message like {selected, tumour} is received, the 3D model manager adjusts the opacity of all 3D anatomy except for the tumour to 0. The logic manager interprets the message and translates it into a format understandable by the animator (Figure 23), indicating that the selected camera should be the tumour camera. This prompts the camera manager to activate the appropriate camera. Now, if a message such as {key, „w"} arrives, the camera control manager responsible for orbitation moves the active camera upwards.

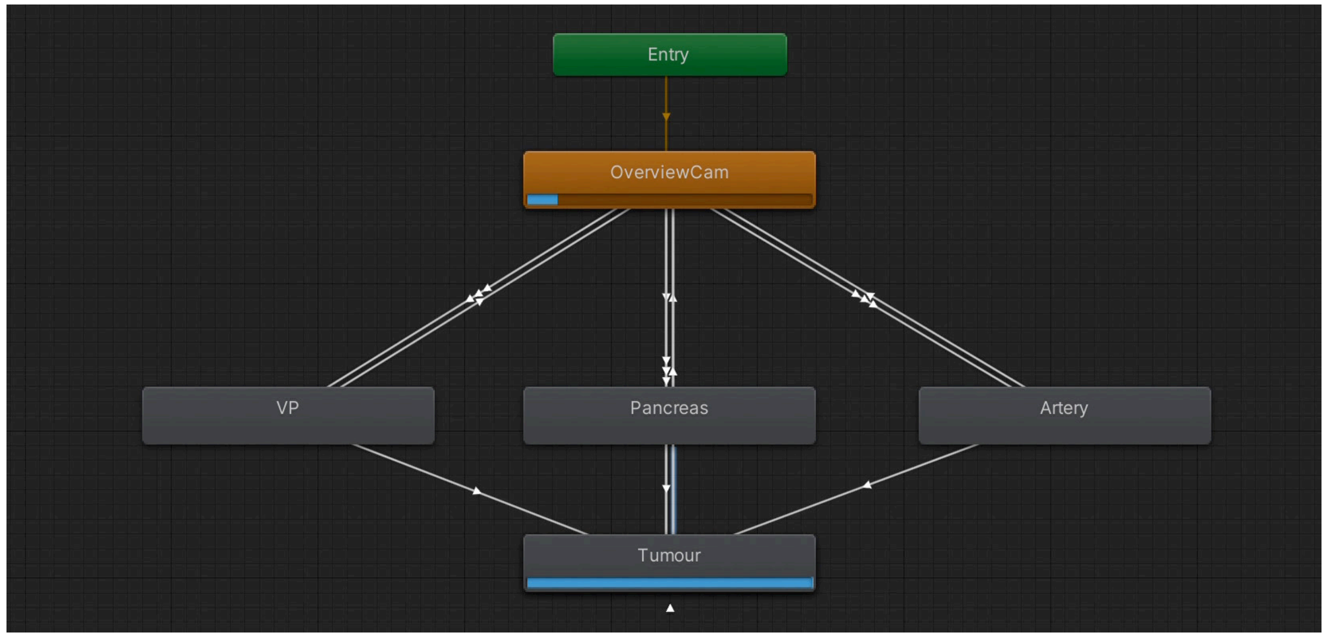


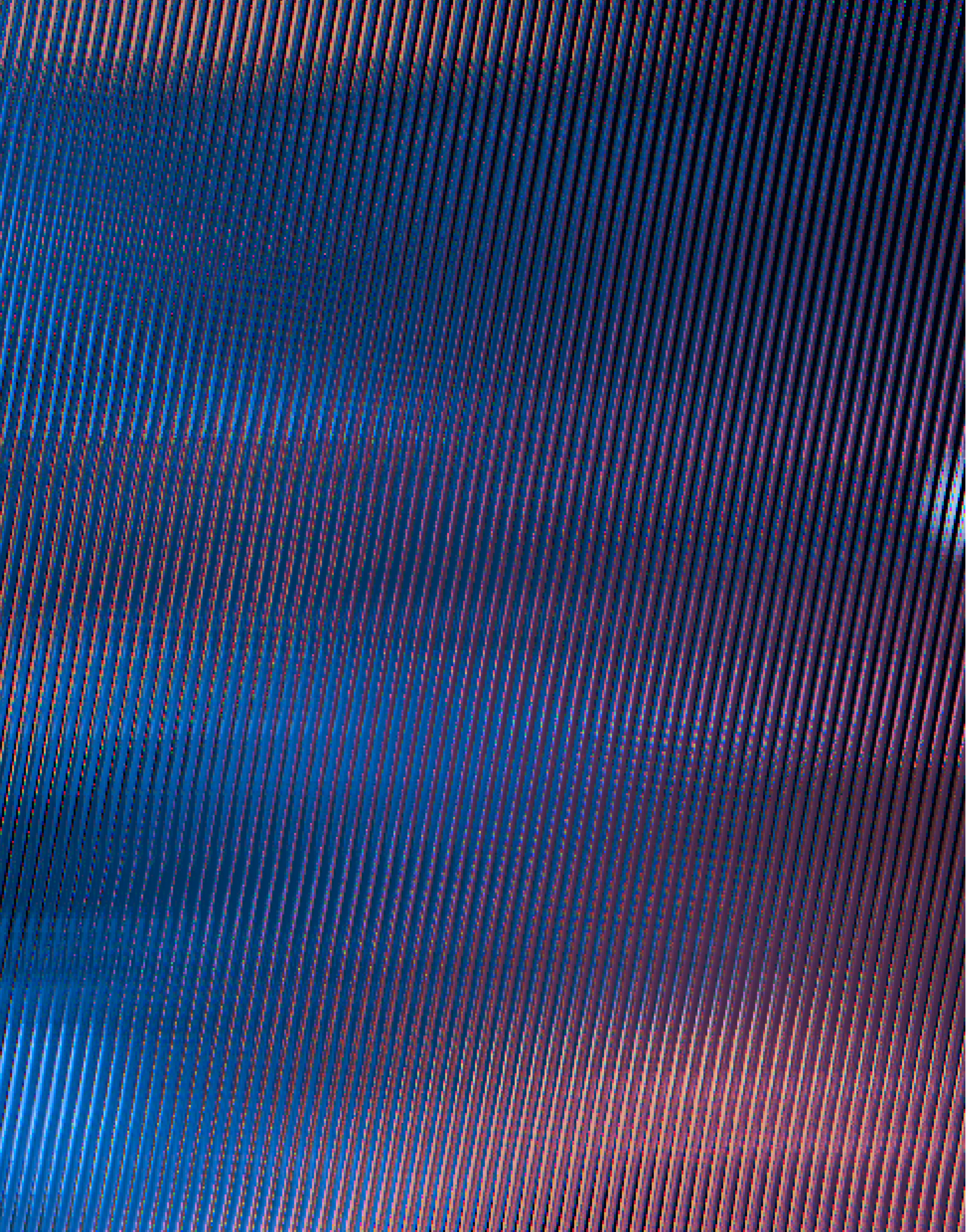
Figure 23. The state logic behind the camera system. It uses an animation module to transition the points of view.

```
You, last month • First commit …
0 references
public void ReadEvent(string type, string message)
{
    if (triggerMaps.ContainsKey((type,message)))
    {
        // Activates the trigger corresponding to the type, message tuple
        targetAnimator.SetTrigger(triggerMaps[(type,message)]);
        Debug.Log("Trigger set ---> " + type + ", " + message + " -> " + triggerMaps[(type,message)] );
    }
}
```

Figure 24. A code snippet of the camera transition manager, which repeats the message received but for the animator system

Technical restrictions

The project featured a restricted selection of organs, limited to those segmented in previous research, resulting in an incomplete representation of all organs. The DICOM viewer prototype was also limited to one slice, which didn't fully capture the surgeon's contextual needs. Unfortunately, due to time constraints relative to the technical complexity involved, the implementation of the slice line design on the 3D model was unfeasible. These shou



CHAPTER 08

EVALUATION STUDY

This chapter delves into the design of the evaluation study involving three expert HPB surgeons and subsequently presents the results, addressing the research questions RQ3 and RQ4 related to the design.

Evaluation study with surgeons

The primary goal of this user study was to assess whether the final prototype allowed surgeons to find important anatomical landmarks and tumour-vascular interactions, if they found it usable and understandable, and if they would introduce it in their workflow. Participants were recruited on a voluntary basis through a contact from the Catharina Hospital. A total of 3 surgeons specialised in hepatopancreatic-biliary agreed to partake in the study in separate sessions (Figure 25). They had between 10 and 25 years of experience in the field, and all had already tested the prototype in an earlier iteration (protocol in Appenix Hv).

Participants were briefly introduced to the surgical context and the prototype, which had a fully-fledged 3D interaction but was reduced on the 2D side, as it only had one slice and no possibility to scroll. The anonymous medical data shown was already clinically assessed, as it came from a previous study from e/MTIC. The surgeons were instructed to perform two clinical tasks (CT) while using the provided prototype, and to think aloud while doing so:

- CT 1: "Inspect the 3D model to find whether there is vessel involvement."
- CT 2: "Navigate the 3D model to find patient-specific anomalies."

Their interactions were video recorded and timed. If a participant would get stuck, small hints were given to help out. Upon completion of the tasks, two clinical questions (CQ) regarding the inspection were asked:

- CQ 1: "Is there vessel involvement? How confident are you?"
- CQ 2: "Are there patient-specific anomalies? How confident are you about this?"

Subsequently, the surgeons had to fill up a System Usability Scale questionnaire. Then, they were asked the following open questions reconnecting to the research questions.

- Q1: "Does this prototype let you satisfyingly visualise the relevant anatomical landmarks and reach the point of view you need to inspect the 3D model? Why (not)?"
- Q2: "Do you feel the need for more / less / other control over the navigation of the 3D model?"
- Q3: "Do you think that the use of the final version of this system might improve (make faster, better, more confident) the detection of anatomical interactions (ingrowth) or anomalies?"

The first two questions were conceived to trigger detailed feedback on usability, user experience and the alignment of the design with the surgeon's surgical planning workflow; while the third question was devised to understand the potential value and application of the prototype.

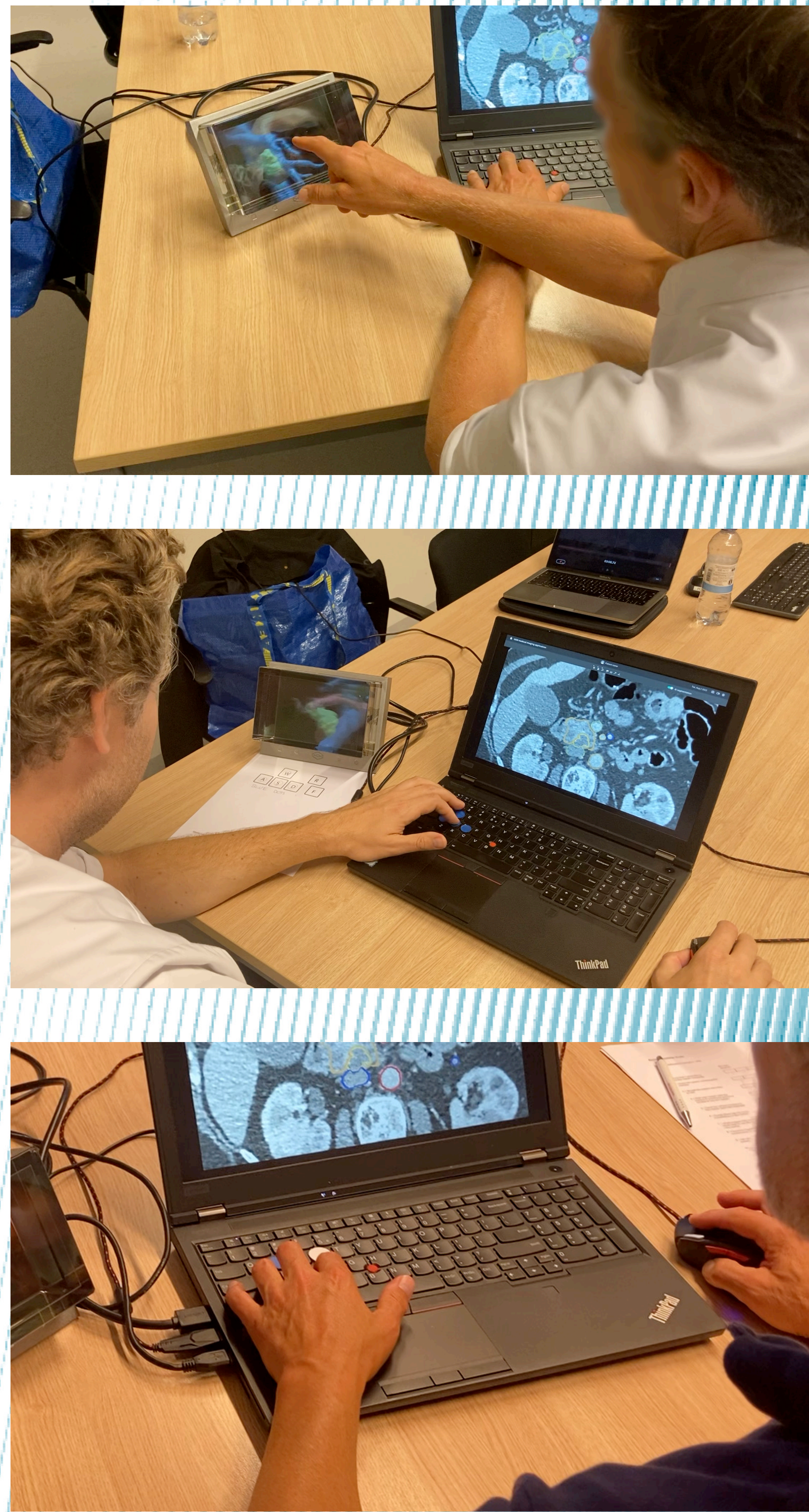
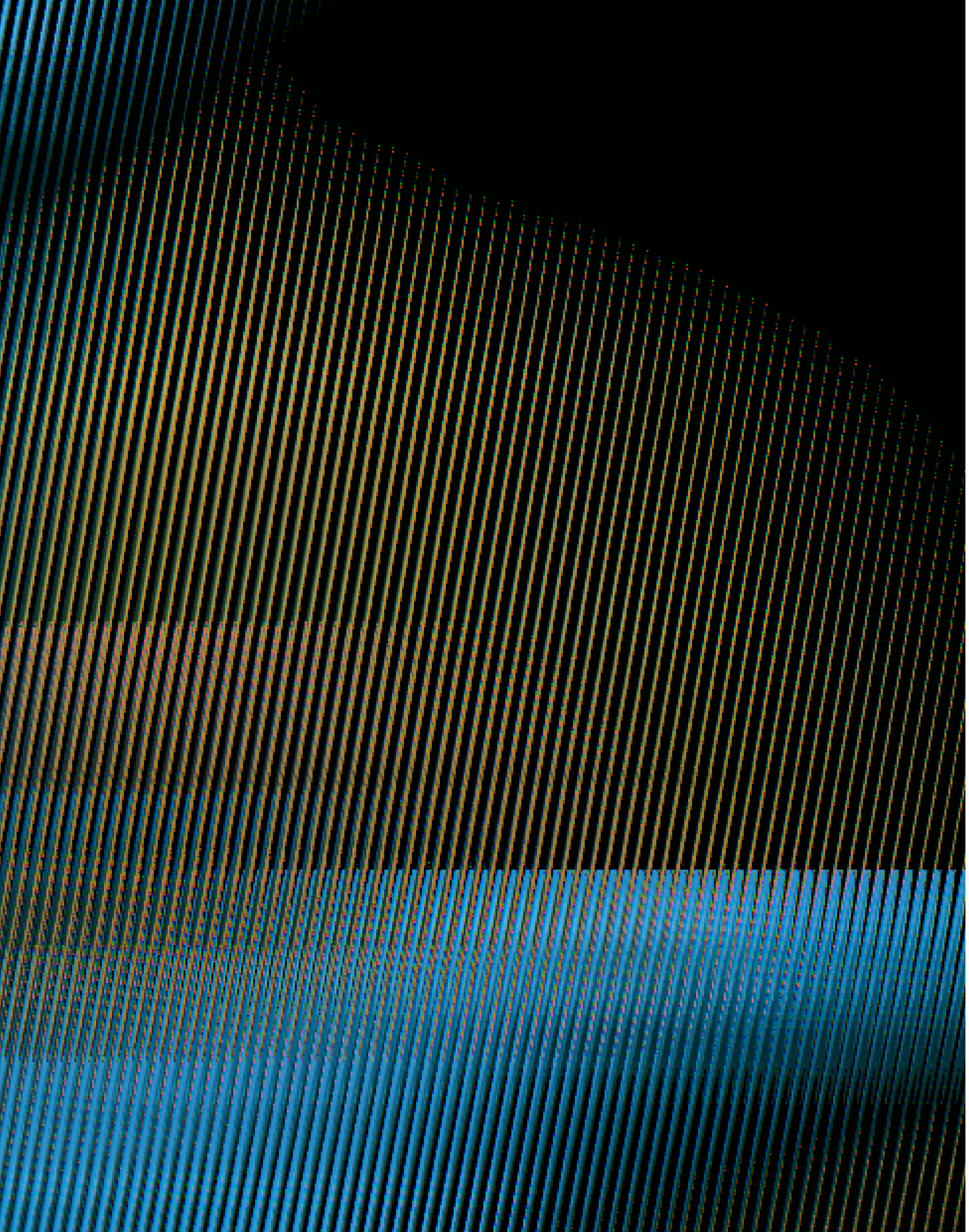


Figure 25. The three expert HPB Surgeons, interacting with the design during the evaluation.



CHAPTER 09

RESULTS

In this chapter, the findings obtained during the evaluation study are presented.

Results

// SUS & Clinical Results

The study participants, consisting of 3 experienced HPB male surgeons, were recruited from the Catharina Hospital. Quantitative data was collected through a SUS questionnaire, by tracking time and recording of the qualitative answers; while qualitative data was collected through recorded semi-structured interviews. Data analysis was performed using the SUS scoring system and averaging the quantitative results, and analysed by clustering into overarching themes.

The quantitative research related to usability yielded the following results: the System Usability Scale (Figure 26) indicated a mean score of 80 and a median score of 78, placing it in the upper „Good" category (Bangor et al., 2008).

Surgeons	Experience (Years)	SUS Score		Mean SUS Score	Median SUS Score
S1	20+	78		**80**	**78**
S2	Approx. 10	88			
S3	20+	75			

Figure 26.Table with results from the SUS questionnaire

Regarding the quantitative data from the clinical tasks (CT1, CT2) (Figure 27), one surgeon, S3, accurately identified vessel involvement in the superior mesenteric vein (SMV) with a high level of confidence. S2, while recognizing vessel involvement, incorrectly identified the vein as the vena cava (VC), and expressed low confidence in this assessment based solely on the 3D model. S1 encountered a bug in the ingrowth visualization, which prevented a thorough assessment of the holographic anatomy.

The surgeons who responded with high confidence took approximately 1 minute to reach their conclusions, while the more hesitant S2 required 3 minutes. All the surgeons unanimously highlighted the absence of some landmarks on the 3D model, imperative for successfully identifying specific anatomy. It took them between 30 seconds and 1 minute of inspection to get to this realisation.

Surgeons	CQ1:Vessel involvement	Approx. Time	How confident
S1	Inconclusive (bug)	1 Min	Highly
S2	Yes, Vena cava	3 Min	Low
S3	Yes, Superior Mesenteric Vein	1 Min	Highly
Ground truth	Yes, SMV		

Surgeons	CQ2:Specific anatomy	Approx. time	How confident
S1	Missing anatomical 3D info	30 Sec	Highly
S2	Missing anatomical 3D info	30 Sec	Highly
S3	Missing anatomical 3D info	1 Min	Highly
Ground truth	Yes		

Figure 27. ßTable with the results of the clinical questions CQ

// Interview Results

Q1: "Does this prototype let you satisfyingly visualise the relevant anatomical landmarks and reach the point of view you need to inspect the 3D model? Why (not)?"

Surgeons were unanimously satisfied with the views they could achieve through orbiting around the vessels. However, they missed crucial vessels needed to check vascular anomalies, such as the right aberrant hepatic artery. These vessels were neither projected in the 3D display nor made interactable on the CT scan (See Figure 28).

Q2: "Do you feel the need for more / less / other control over the navigation of the 3D model?"

The direct interaction with segments on the CT scan to select organs, especially the ability to turn them on and off, received positive feedback from all participants. However, both surgeons S2 and S3 mentioned an issue with the segment selection behaviour on the scan: if the main trunk of a vessel is selected, the other branches should also be displayed, to prevent any potential oversight. Additionally, using the keyboard for manipulation was considered less preferable compared to mouse interaction by S1 and S3, who had experience with the past iteration of the integrated imaging workstation that featured mouse interaction. In contrast, S2 found the keyboard interaction acceptable (See Figure 28).

Q3: "Do you think that the use of the final version of this system might improve (make faster, better, more confident) the detection of anatomical interactions (ingrowth) or anomalies?

Two surgeons, S2 and S3, expressed their willingness to integrate the system into their daily workflow, particularly during surgical planning and preparation. They also believed that their confidence levels would increase with the use of the prototype. Notably, S2, the least experienced of the three surgeons, mentioned that the system could potentially reduce preparation time. Both S2 and S3 emphasized that the navigation system could significantly enhance the workflow, particularly for novice and intermediate surgeons. (See Figure 28)

Q1

Regarding satisfaction view reachable with the orbiting system (Q1)	Vessels missing in the 3D (Q1)
S1: "And, [if] this shows more, vessels. [...] Then yes, I think, [the system] has additional value to show vessel involvement." S2: "Yes, and in the 3D, rotating around the model" S3: "Yeah, definitely [did manage to find the angles that I wanted with the 3D]. "	S1: "The vessels which have vascular abnormalities are not displayed. So that's a limitation.", "And, this shows more, vessels. So the hepatic artery, gastroduodenal. Then yes, I think, it has additional value to show vessel involvement. " S2: "What I say, the common hepatic duct is missing now, but it's because of the slice, yeah?"; S3 "It's hard for me to tell where, of course, there can be on CT scan, there can be an aberrant right hepatic artery, but it doesn't show up. Okay. It's not one of the ones that you can select here, right? "

Q2

Regarding CT scan to interact with segments (Q2)	Keyboard vs. Mouse (Q2)	Vascular branches selection behaviour (Q2)
S1: "That's good, that's better"; S2: "You know, with the selection. Yeah, it works very well. Especially on and off of the tumour. It's nice."; S3: "being able to directly select or, or deselect. Yes, I think it's important to do it like that."	S1: "So that's okay. But yeah, I liked it with the mouse." S2: "Rotating the model with the buttons is okay" S3 "Like having this keyboard, it would be much better if I could choose a mouse" "I think in the end we should be able to control everything with the mouse"	S3 "So, but if I say, okay, I'm starting to look at the arteries and I forget to include this one, I will never see it. So maybe you have you should have an option, show all arteries that you're sure that you have clicked all the different" S2: " I guess you'd need to select the second branch here. So when you select something you expect to see the whole"

Q3

Improved workflow for novice and intermediate surgeons. (Q3)	Surgical planning (Q3)	Higher confidence (Q3)
S2: "I think for the very experienced surgeon, it won't speed up. But for the intermediate and the novice, it will help". S3: "Especially for people who are less experienced in watching CT scans or doing surgery, I think it would, it could greatly improve the learning curve of interpreting".	S2: "For me, especially before surgery, and so also before patient consultation, when we will discuss this surgery and meet first if it is technically feasible, then I would also reuse it" S3 "Planned surgery, I think that would be if you can do it beforehand, that would be great. We try to make this kind of pictures in our minds by looking to the CT scan. So, if you don't, it will never be as good, I guess as it would be on the assess the computer or visualize it. So I think it will be improvements of your 3D planning."	S2: "More confidence about my interpretation of a 2D scan to 3D and faster, I think." S3: "This makes you more confident. That's what you reconstruct in your mind. That is like the truth that you'll encounter during surgery. Yes, I think so, yes."

Figure 28.Themes which emerged from the analysis of the open questions.

// Key Insights

Selection behaviour of vascular branches

The interviews and recorded videos suggest a need for improvement in how branches are selected on the CT scan. Surgeons faced challenges when selecting different branches, possibly because of their smaller diameter. Additionally, S2 and S3 expressed concerns about the possibility of surgeons overlooking deselected branches (Figure 28), which could be anatomical variants and pose risks during surgery. One potential solution to address these issues might involve updating the system to display all branches connected to a selected vessel.

Mental model in selection and camera state-change

Although the surgeons found the system usable, observations exposed a partial understanding of segment selection and camera state switching. They intuitively used these features but encountered issues getting stuck in one state without easily returning to the overview view. For example, S3 requested a „home" interaction for quick access to the overview camera, and S1 and S2 also had difficulties and remained locked into one camera state. Additionally, none of the surgeons fully grasped the existence of multiple cameras, suggesting a potential gap in their mental model (Norman, 2013). This issue may arise from the dual function of selection of a segment, which serves both to control 3D opacity and to switch cameras. To address this, employing metaphors, a successful strategy in medical visualization (Preim, 2011), could help surgeons better understand and navigate the available cameras.

Hovering

The surgeons generally had mixed feelings about the hovering interaction, with comments like „OK, but not especially useful" (S1) and „It might be handy" (S3). However, observations indicated that S3 was somewhat confused by the hover effect, as it interfered with his ability to turn off a vessel. These insights might suggest the need to explore alternative design directions for the hover interaction.

An adapted workflow suggestion

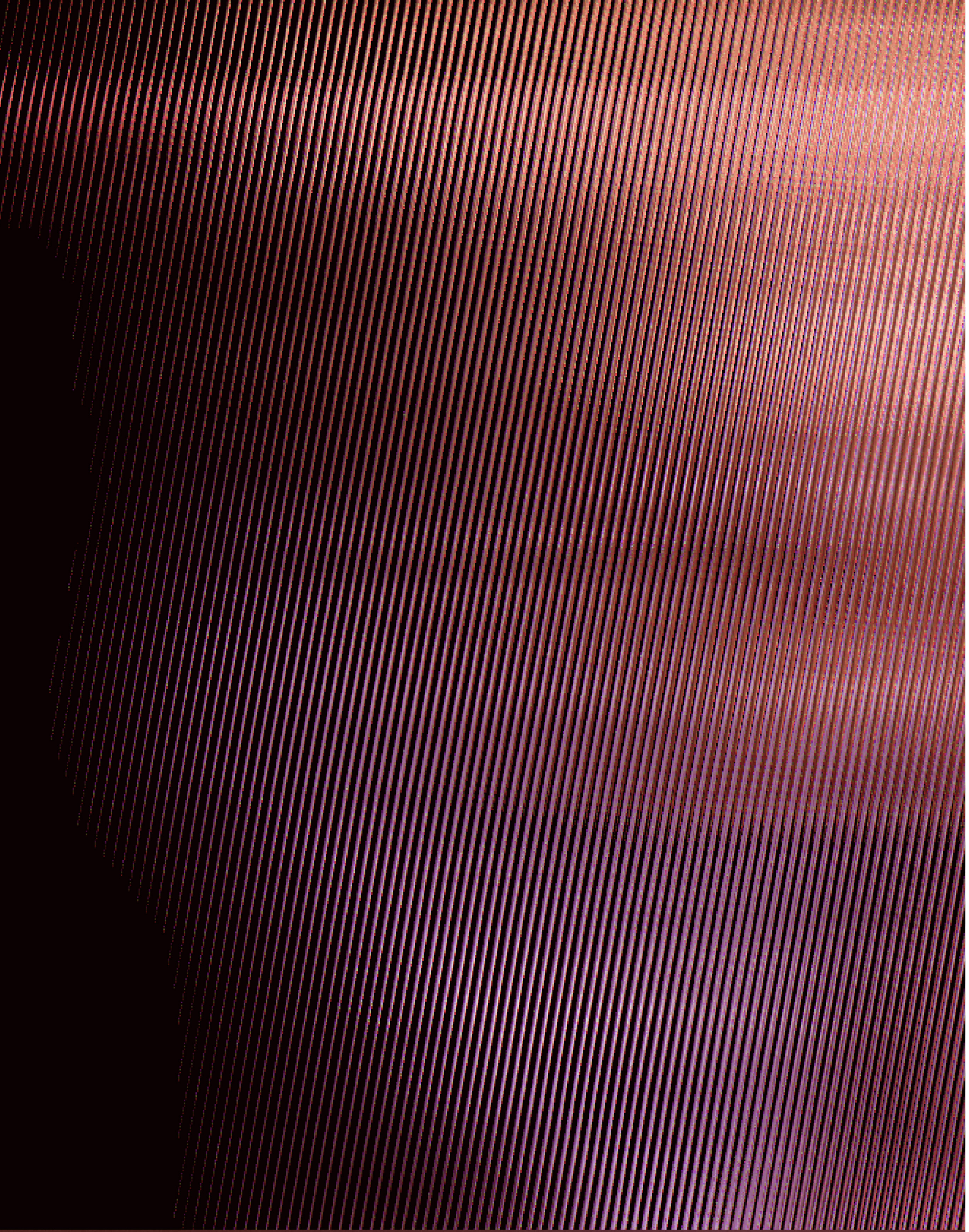
Surgeon S1 demonstrated a clear vision of how to integrate the 3D navigation system into his surgical preparation and diagnosis workflow. S1's approach to finding patient-specific anatomy "in one blink of an eye" would involve:

1. Scrolling through CT scan
2. Choosing suspicious anatomical landmarks
3. Examining them in 3D

In cases of tumour-vessel involvement, S1 would employ a slightly different approach:

1. Identify a candidate anatomical landmark on the CT scan
2. Display synchronously it across all available medical visualisations, including various CT scan phases (medical glossary) and the 3D model, and then switch focus between these modalities for detailed inspection.

This workflow could be considered by designers for future iterations of the prototype, especially when fleshing out a complete interaction flow of surgical planning.



CHAPTER 10

DISCUSSION

In this chapter, we address the design-related research questions, RQ3 and RQ4. We also position this thesis in relation to previous research, discuss the implications of the results, and provide design guidelines and research recommendations. Finally, we conclude by highlighting the limitations encountered during this work.

Discussion

// Answering the Research Questions

RQ3: How can one design a 3D navigation system to support surgeons in finding crucial anatomical landmarks and tumour-vascular interactions?

This research showcases a robust interaction method designed to assist surgeons in locating anatomical landmarks and examining tumour-vasculature interactions. It has resulted in a solid median System Usability Scale (SUS) score of 78 for the aggregated navigation system. These positive outcomes can be attributed to interactions such as orbiting around vessels and selectively enabling or disabling segments on the CT scan. Furthermore, the interviewed surgeons expressed increased confidence in using the system, particularly novice and intermediate users. However, the camera state-change mechanism lacks clarity and requires improvement. Additionally, due to limitations in available 3D vessel segmentations, a comprehensive evaluation of the system's effectiveness in identifying anatomical variations couldn't be conducted, despite promising indications from interviews regarding the overview camera's potential in this regard.

RQ4: How can one seamlessly integrate 3D medical visualisation into conventional 2D medical imaging?

Assessing primarily based on overall usability, indicated by the „good" SUS score and reduced difficulties with the 3D interface, might suggest that integrating the CT scan as a 3D navigation tool and synchronizing interactions between the 2D and 3D interfaces contributed to seamless system integration. However, it's important to note that this question cannot be definitively answered based on the evaluation study alone. The technical limitations, such as having only one slice of the 2D and thus compelling surgeons to primarily interact with the 3D interface, weaken the aforementioned statements. A more conclusive answer to this question may become attainable in future iterations of the prototype when full 2D integration is incorporated.

Connection to Previous Research

This thesis contributes to the research and application of 3D technology in oncology. It distinguishes itself by adopting a unique approach to surgical planning, focusing exclusively on the perspective of surgeons as the primary stakeholders and employing a novel autostereoscopic display, in contrast to the collaborative and VR-based approaches followed by others (Bashkanov et al., 2015; Boedecker et al., 2021; Kenngott et al., 2022; Kumar et al., 2020). Additionally, it conducts "surgeon-centric" research, meticulously dissecting the surgical planning workflow of HPB (Hepatopancreatobiliary) surgeons using a designerly approach. This approach enables the identification of crucial design and research factors related to surgeons and their unique workflow. From an HCI perspective in medical visualization, this research aligns with the suggestions made by Preim (2011) while adding refinement in the form of specific workflow guidelines tailored to the context of surgical planning and personalized approaches. Furthermore, this thesis ventures beyond the confines of medical literature, incorporating elements such as the successful „StyleCam" techniques into the prototype's design. This integration possibly marks one of the initial applications of such techniques within the realm of healthcare, exemplifying the potential for cross-disciplinary collaboration and innovation.

Implications of the Results

The positive feedback from the surgeons shows promise for the project stakeholders, e/MTIC, in pursuing further iterations with a navigation system where 3D and CT scans are connected through the selection of segments to (at least partially control) the 3D model. However, the use of mouse instead of keyboard input for the orbitation control needs to be re-integrated, and the flow of the experience needs to be fully fleshed out. The list of important landmarks should be used to improve the 3D model.

The research insights and the derived design opportunities, complemented by the identified personal approaches of surgeons to locating landmarks, provide a valuable foundation for future design and academic research centred around surgeons. There is also potential for future research to delve into more granular activities like task analysis and incorporate eye-tracking technologies for a stronger HCI approach. Future designs must prioritize the prevention of design-enhanced risks, as exemplified by the issue with the selection behaviour of vascular branches. Neglecting to visualize certain critical branches could lead to dangers during laparoscopic surgery, especially for novice surgeons.

// Design Guidelines

n the pursuit of future design improvements, several key guidelines have emerged. For future design considerations, addressing the issue of the selection behaviour of vascular branches is paramount. One potential solution involves updating the system to display all branches connected to a selected vessel, providing surgeons with a comprehensive 3D visualization of relevant branches and thereby enhancing clinical safety. However, designers should bear in mind that this modification may reduce the system's flexibility.

Additionally, it is advisable to tackle the problem of establishing a clear mental model for selection and camera state changes in future designs. This could be achieved by incorporating metaphors, such as explicitly indicating when the user enters a „Tumor view" or an „Arterial mode". Such metaphors have proven effective in medical visualization (Preim, 2011) and can aid surgeons in better understanding and navigating available camera perspectives.

In terms of orbitation control around organs, future designs should explore the use of mouse interaction, as suggested by the evaluation results. Design possibilities abound, including the re-integration of direct 3D interaction of past IIW iterations or utilizing the CT scan as an interface, allowing users to click on a segment and drag the mouse (similar to Speed-coupled Flying with Orbiting, see literature chapter). Regardless of the chosen approach, it should be seamlessly integrated with interactable scans.

Lastly, for minor points to consider in future design efforts, enhancing guidance throughout the interaction, developing onboarding processes, incorporating surgeon S1's adapted workflow suggestion, and reevaluating the use of hover (potentially not suitable for opacity control) can collectively contribute to the overall improvement of the system's usability and effectiveness.

// Future Research & Limitations

Future endeavours could involve a broader spectrum of participants, such as less experienced surgeons or medical practitioners from peripheral hospitals. Additionally, the effective research-through-design approach should be continued, as it facilitates engagement with surgeons by providing tangible prototypes for feedback. This approach has proven highly effective within the surgical environment. To further enhance our understanding of the approaches outlined by the questionnaire's results, incorporating eye-tracking technology into future research could be valuable. This would offer deeper insights into participants' interactions and decision-making processes during medical visualization tasks.

Several constraints impacted this study. Technical limitations constrained the full integration of interactable segments into CT scan slices, limiting the range of interactions assessed. Additionally, the absence of a complete 3D model necessitated the inclusion of crucial vessels. Time constraints hindered the implementation of all surgeon feedback suggestions, notably the projection of the slice onto the 3D model. This feature had been mentioned at various points in the research but couldn't be fully realized within the allotted time frame. Evaluating the 3D navigation system independently, without surgeons considering the prototype as a whole, posed challenges due to the intricate nature of the interaction, which requires surgeon testing rather than layperson evaluation. Moreover, conducting research in the healthcare sector, particularly with busy surgeons, presented general difficulties. Establishing and nurturing relationships, as well as persuading surgeons to participate in the research and testing, were time-consuming endeavours that caused delays in the thesis plan.

// Main Takeaways

This thesis has generated a multitude of insights, but the one overarching message encapsulates the essence of this work. It underscores the importance of „small steps" in driving innovation within the healthcare sector, particularly in deeply ingrained workflows and complex settings. The key takeaway is the importance of striking the right balance when integrating technological advancements into existing workflows and, on a deeper level, interaction processes. By dissecting how surgeons work with medical imaging, specifically their methods for identifying critical anatomical landmarks within scans, this research has demonstrated the value of designing interactions that augment their existing practice and align with their intuitive understanding. An example of this is the ability to select an anatomical landmark directly from its segment within the scan.

In conclusion, this work presents a viable direction and concrete next steps in the development and design of the integrated imaging workstation, highlighting the potential of the surgeon-friendly 3D navigation system to enhance surgical planning practices. Addressing the identified limitations and continuing further research in this area can contribute to an improved, human-centred understanding of the context and refinement of the design.

CHAPTER 11

Conclusions

This thesis unravels the context of surgical planning of complex cases of pancreatic cancer, particularly to understand how hepatopancreatic-biliary surgeons use medical imaging and how they approach finding anatomical landmarks and tumour-vascular interactions. Further, the design challenges of supporting surgeons in finding these landmarks or vascular interactions and seamlessly integrating 3D medical visualisation into conventional 2D scans are tackled.

The investigations uncover several design opportunities, ranging from identifying essential landmarks for surgical preparation to gaining insights into surgeons' personal approaches, such as the „vertical scan" and „zoom in and out" techniques. They also provide a comprehensive understanding of their interaction methods, particularly the surgeon's reliance on scrolling to reconstruct a 3D image in their mind. These findings lay the foundation for future design endeavours, emphasizing the need to minimize disruption, strike a balance between control and interaction speed, and effectively visualise both detail and overview. The design phase yields promising results, especially concerning the direct selection of segments on the scan to turn them on and off. However, it also highlights the need to revisit the orbiting interaction mechanism, potentially shifting from keyboard input to mouse interaction. Additionally, suggestions are made to explore direct interaction on the scan alongside direct 3D interaction and incorporate metaphors to enhance the mental model of the camera system. Updating the behaviour of branch selection is also recommended to prevent confusion.

In terms of contributions to the field, this research offers a human-centred exploration of surgical planning for complex pancreatic cancer cases, providing a series of design opportunities to guide future research. It also introduces a functional prototype system that enables surgeons to navigate 3D medical imaging with ease and efficiency, yielding valuable design insights for future iterations that can be of great use to e/MTIC in their upcoming projects. It's important to acknowledge the limitations of this work. Full integration of the prototype with a CT scan proved unfeasible due to constraints, and certain desirable features had to be omitted due to time limitations. Engaging healthcare practitioners, especially surgeons, for research purposes is also challenging, given their limited availability. Therefore, a research-through-design approach is recommended for future endeavours, as it tends to garner more participation when tangible prototypes or demonstrable results are presented.

In conclusion, it is hoped that this thesis will serve as a valuable resource for e/MTIC, Philips, and designers working on integrating 3D technology and interaction into the workflows of highly specialized medical practitioners. Additionally, it aspires to encourage further research from a human-centred perspective within the healthcare sector, particularly in the realm of oncology.

CHAPTER 12

Reflection

I'm sincerely grateful for the opportunity to be part of this project, where my passion for mixed reality technology converged with the complexities of healthcare. From the beginning, this project aligned with my aspirations when I joined TU Delft's Design for Interaction program. It immersed me in a world of research and design, working alongside a diverse group of stakeholders - from expert TU Delft academics to medical professionals at Catharina Hospital Eindhoven and innovators at Philips Experience Design.

As I delved into the intricacies of surgeons' challenges, I gained valuable insights and deep respect for their work. Collaborating with colleagues at Philips, in an innovative setting, proved both motivating and transformative. It improved my prototyping and coding skills for mixed reality solutions, particularly focusing on an autostereoscopic display. While the journey had its share of hurdles, my supervisors' unwavering support, along with perseverance, led to a positive outcome. This experience enriched my skills as a designer and my empathy as an individual, preparing me for future career endeavours.

In closing, I extend my gratitude to those who played a crucial role in this journey. Your support, guidance, and collaboration have been instrumental. As I move forward, I carry not only new knowledge and skills but also a sense of fulfilment and dedication to design. This experience reaffirms my belief in the power of design, particularly in healthcare. With renewed enthusiasm and a broader perspective, I look forward to applying these insights and experiences to future challenges in my career. Thank you for being part of this journey.

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APPENDIX

Personal Project Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Frison
initials: SW given name: Sebastian Walter
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): IPD / ★ DfI / SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: ★ Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Evangelos Niforatos dept. / section: SDE/HCAI
** mentor: Maarten Wijntjes dept. / section: HCD/HICD
2nd mentor: Luc Geurts
organisation: Philips Experience Design
city: Eindhoven country: Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair: Evangelos Niforatos date: 23 - 03 - 2023 signature: Evangelos Niforatos (Digitally signed by Evangelos Niforatos Date: 2023.03.23 15:26:07 +01'00')

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC
Of which, taking the conditional requirements into account, can be part of the exam programme: 27 EC
List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed
NO missing 1st year master courses are:

name: Robin den Braber date: 30 - 03 - 2023 signature: Robin den Braber (Digitaal ondertekend door Robin den Braber Datum: 2023.03.30 ... +02'00')

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED / NOT APPROVED
Procedure: ★ APPROVED / NOT APPROVED

- also approved for Medisign

comments

name: Monique von Morgen date: 04 - 04 - 2023 signature:

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 2 of 7
Initials & Name: SW Frison Student number:
Title of Project: Surgical planning for pancreatic cancer: a holographic interaction

Personal Project Brief - IDE Master Graduation

TU Delft

Surgical planning for pancreatic cancer: a holographic interaction — project title

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

start date 23 - 03 - 2023 — 04 - 09 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Pancreatic cancer is one of the deadliest cancers in the world, with only one out of every ten patients living more than five years after diagnosis. Surgery (pancreatoduodenectomy) is the only curative treatment for patients diagnosed with pancreatic cancer. The assessment of the resectability of the tumour, based on Computed Tomography (CT) scans, can be critical and demands expertise.

This complex medical process involves many different stakeholders: radiologists, surgeons, oncologists, gastroenterologists, vascular surgeons and the surgical teams that play different roles in other parts of the medical pathway. Specifically, this graduation project will dive deep into the workflow of surgeons during pancreatoduodenectomy planning.

The project's scope is enabled by the Eindhoven Medtech Innovation Center (e/MTIC), an ongoing collaboration between Philips, Catharina Ziekenhuis Eindhoven and TU/e. One of the project's aims is to innovate healthcare processes with human-Artificial Intelligence (AI) collaboration.
This collaboration has already yielded the development of a prototype that enhances the current approach of the surgeons with an AI-generated 3D representation of the CT's on an autostereoscopic display: 3D visualisation of the organs seems to have potential, possibly empowering surgeons to have a faster and more accurate evaluation.

One of the many challenges left to be tackled is that the surgical planning interaction is still unexplored, as the current prototype gives new, three-dimensional affordances. Still, it isn't yet fully adapted to the surgeon's workflow.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images

image / figure 1: The current prototype: 2D - AI segmented CT scan & 3D visualisation of the organs.

image / figure 2:

Personal Project Brief - IDE Master Graduation

TUDelft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The scope of this graduation project encompasses the surgeon's workflow of surgical planning, in particular for pancreatoduodenectomy. As a secondary factor, I want to keep in mind the communication and collaboration aspect of sharing and explaining the devised plan to the surgical team, surgeons in training or patients.

The solution space is strongly influenced by the technology: it will use an autostereoscopic display and the interactive prototypes will be developed with a 3D game engine. The existing prototype will also influence the direction of the design, which will be based on the interplay of 2 dimensional CT scans segmented by AI on a desktop screen and the 3D reconstruction of the organs on the autostereoscopic display.

Combining these factors brought me to the following research question: How can 3D interactions on autostereoscopic displays enhance the current surgical planning for pancreatoduodenectomy?

A broader, secondary question arising is: How can this system be designed to support surgeons' decisions and collaboration with other experts in the area of pancreatic cancer treatment? How will the surgeons' understanding of the uncertainty of AI segmentations play a role?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The ultimate goal of this project is to design an interaction on a 3D, autostereoscopic display, to enhance (make faster, more precise) the surgical planning workflow of surgeons for pancreatoduodenectomy - with the 3D data visualisation afforded by the technology.

Firstly, I'm going to research the workflow, the crucial information and the thought process of surgeons planning a pancreatoduodenectomy. I plan to unveil this insight through interviews, observations, co-creation sessions and adjacent literature. The use of eye-tracking technology will be considered for this and the evaluation phase.

Further literature research will be dedicated to the autostereoscopic technology used.

Then, I'm going to move to a prototyping phase: this is going to be structured in short development-feedback iteration loops (brainstorm, design, test, document) to diverge and produce as many 3D ideas as possible for the surgeons to evaluate. These prototypes will be in form of low-fidelity illustrations, and rough 3D designs with basic interaction embedded - enough to create the bare functionality to be tested.

After, these concepts will be (iteratively) condensed into two high-fidelity prototypes - which I want to design as an interactive experience that integrates into the researched surgeons' workflow and that can be evaluated in a realistic simulation setting (with 3D display). Depending on time, some level of integration with the existing prototype will be aimed for.

Initials & Name SW Frison Student number

Title of Project Surgical planning for pancreatic cancer: a holographic interaction

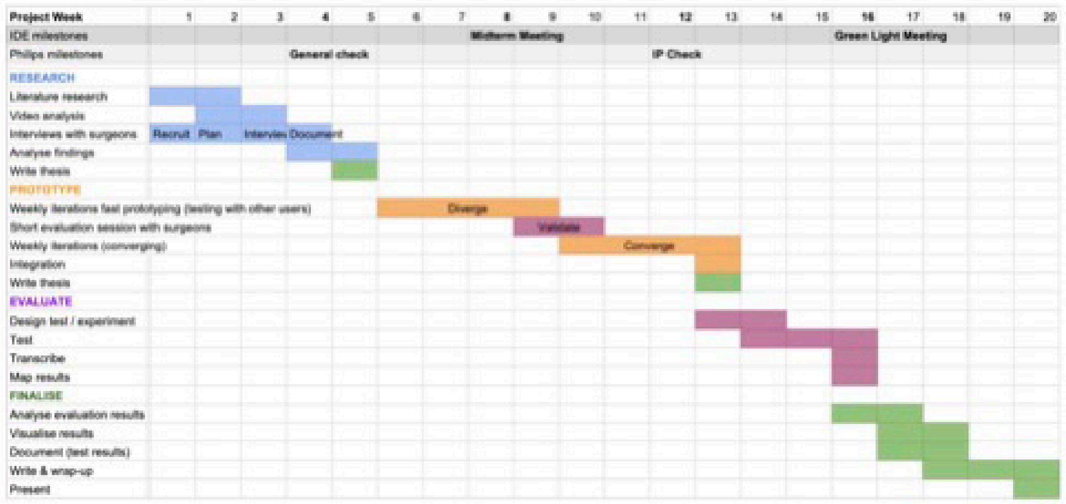
Personal Project Brief - IDE Master Graduation

TUDelft

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 23 - 3 - 2023 4 - 9 - 2023 end date



RESEARCH (Weeks 1 - 5):
Literature research (desk research), Video analysis (from preexisting interviews). Recruit (also for the final evaluation), plan & design study protocol, and execute qualitative interviews or co-creation sessions with surgeons. Write chapters for the thesis.

PROTOTYPE (Weeks 6 - 13):
Weekly fast prototyping iterations (design a concept in 3D, test it, analyse results & document). Diverging (focus on quantity) and speculative ideas: weeks 6 - 8. Short evaluation of all prototypes with surgeons on week 9. Converging (condensing the promising ideas into a few HI-FI prototypes): weeks 9 - 13. Write chapters for the thesis.

EVALUATE (Weeks 14 - 16):
Design session experiment & study protocol. Test with as many surgeons as possible in a realistic setting, possibly with real data. Document. Write chapters for the thesis.

FINALISE (Weeks 17 - 20):
Analyse data, document learnings and put all text together. Prepare presentation.

Initials & Name SW Frison Student number

Title of Project Surgical planning for pancreatic cancer: a holographic interaction

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

This project combines 3 of my big passions as a designer: extended reality (XR) technologies, the medical field and the challenge of innovation: how to approach the introduction into existing practice of new interactions brought by novel technology?

I am eager to utilize my knowledge gained from Context Mapping and conduct human-centered research, while also taking up the challenge of working with a complex user group such as surgeons. I plan to dissect their surgical planning workflow and develop an understanding of their mindset, possibly uncovering overarching themes.

Furthermore, I want to train my fast prototyping skills that I learned in the Interactive Design Technology course, and parallelly build up my 3D interaction prototyping skills.

Finally, I'm excited to collaborate on a project within a larger company, such as Philips, and to explore the potential applications of XR technology in the medical field.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

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