Bachelor’s Thesis in Biomedical Engineering

Benefit of a virtual reality rapid room planning application in marketing and sales of high involvement medical devices – ergonomics, user acceptance and profitability

by Michael Lorentschk

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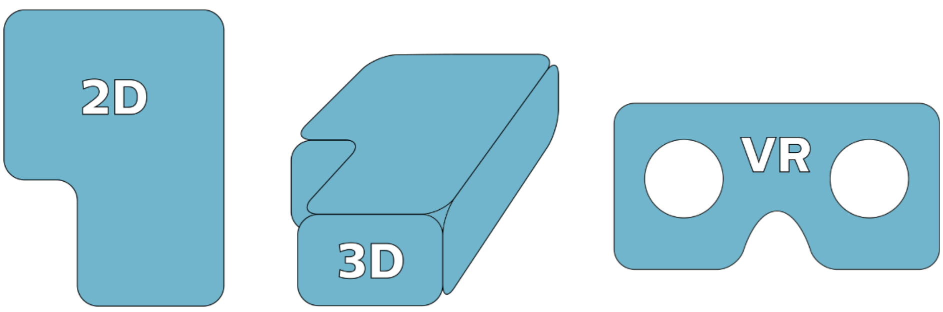

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Abbreviations

VR	= virtual reality
AR	= augmented reality
XR	= extended reality
HMD	= head-mounted display
VIMS	= visually induced motion sickness
UX	= user experience
GUI	= graphical user interface
CGI	= computer-generated imagery
CAD	= computer-aided design
B2B	= business-to-business
B2C	= business-to-consumer
RRPT	= rapid room planning tool

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0. Abstract

The purpose of this work is to evaluate the overall applicability of a rapid room planning tool including a virtual reality visualization mode for a room planning use case in the field of marketing and sales of high involvement medical devices, such as X-ray imaging systems. Four main aspects are identified and evaluated:

- The benchmark of VR applications in the field of high involvement marketing and sales, including B2B and B2C use cases.
- The potentially savable planning iterations and the associated costs within a room installation process, based on literature review of expert opinions in comparable fields.
- The degree of usability of the application, to which extent potential users can create and manipulate room layouts efficiently and without explicit training in advance – assessed in observed user tests with Philips Healthcare employees. Additionally, an employee survey was conducted.
- Customer acceptance regarding the concept of VR visualization and the possibly resulting improvement of visual imagination of device proportions in the anticipated environment in comparison to traditional means of product presentation (pictures, videos, real product) – assessed with healthcare professionals.

The benchmark results reveal a multitude of already widely used VR applications in marketing and sales, especially factory planning is considered as a comparable high involvement use case. Subsequently, increased profitability in factory planning can be extended to medical room planning in form of increased efficiency through the reduction of iterations. The overall evaluation of the rapid room planning tool shows a high degree of usability and acceptance among test users and customers. Survey results are independent of customer proximity and age. This work concludes with recommendations for further development and the creation of additional content for the application.

1. Introduction

“At the core, virtual reality is a human experience. The technology is purposefully designed to take advantage of the human information processing system – to mimic how we interpret the world around us. As the famous Harry Houdini describes: What the eyes see and the ears hear, the mind believes.” [Berg and Vance 2017]

What if this illusory layer of reality would commonly accompany and support different stages of any given planning and decision process, naturally providing a more visual and experiential foundation in a helpful level of detail?

An easily accessible, usable and portable virtual reality solution could effectively and efficiently support medical room planning projects at an early stage. In this work, the applicability of a rapid room planning tool using smartphone-based virtual reality (details in chapter 1.4.) is examined.

1.1. Definition of VR

Virtual Reality (VR) is a technology that enables users to immerse in and interact with a virtual environment: “VR provides a computer-generated 3D environment that surrounds a user and responds to an individual's actions in a natural way. This is usually done through an immersive head-mounted display (HMD) that blocks the user's entire field of vision. Gesture recognition or handheld controllers provide hand and body tracking.” [Gartner 2017b]

VR is not to be seen as a standalone technology or as opposed to Augmented Reality (AR). AR enhances the real world with computer-generated imagery (CGI). Both technologies are rather part of the same continuum of extended reality (XR) media, or *immersive computing spectrum*, where the level of immersion is the central differentiator. Immersion refers to the illusion of being part of a virtual world and interacting with it in real time (so with minimal latency) [Zabel and Heisenberg 2017]. The XR spectrum basically includes:

the real environment | screen-based media → AR → VR

The level of immersion increased from screen-based media to VR. The original idea of the virtuality continuum was postulated including other intermediate forms [Milgram and Kishino 1999], but the essence concerns AR and VR.

VR makes the usage environment (where the user is located with the VR system) completely independent of the target environment (what the user wants to experience or simulate). This is not possible with AR, where the CGI always overlays an actual camera view of the target environment.

The VR hardware platforms can be divided into *low-end VR, mobile VR and full-feature VR* [Pagel and Hauck 2017a]:

Low-end VR most prominently includes Google Cardboard (released 2014) and other very simple mounting devices for any smartphone (or tablet). They do not support any kind of extra controlling device but in some cases, the user can forward touch gestures to the smartphone screen via magnetic or mechanic levers or buttons, but most commonly the user's head movements serve as only means of interaction with the virtual environment.

The second category of mobile VR is based on smartphones as computing unit as well, but users can interact with the virtual world via handheld wireless controllers. Samsung Gear VR (released 2015) and Google Daydream (released 2017) fall into this category.

Full-feature VR refers to extensive systems that use PC workstations as computing units, such as Oculus Rift and HTC Vive (both released 2016). The graphical rendering quality and frame rate is superior compared to low-end or mobile VR. Additionally, the user's absolute body position can be tracked with external sensory systems, allowing natural walking on a definite floor area to be translated into movement within the virtual environment. At the same time, this complicates the hardware setup for full-feature VR, whereas low-end and mobile VR do not require a comparable free floor space. This circumstance makes low-end and mobile VR easier to set up and more convenient for short-time utilization sessions and in confined spaces.

1.2. Awareness and dissemination of VR in society

The basic concept of immersion in virtual environments dates back to 1962, when *Sensorama* is created: a stationary and passively experienced device that could simulate virtual layers of pictures, sound, wind and scent. In 1982, the term “virtual reality” is mentioned for the first time [PwC 2016]. In the early and mid-1990's, HMD-based VR is already being used in the military aviation and aerospace sector.

In the consumer domain, VR receives little attention and popularity at that time: Nintendo, Atari and Sega all fail to successfully launch consumer HMD hardware. In 2012, a $ 2.5 million *Kickstarter* campaign for *Oculus Rift* encourages both users and developers to make another attempt of establishing popular consumer HMD hardware. With this milestone, the awareness of VR in society has increased steadily. Various following announcements and market launches of other hardware platforms and software products further expanded the possibilities and expectations in this technology. Figure 1 shows the worldwide internet (Google) search frequency of the topics of VR and AR [Google Trends 2013-2018].

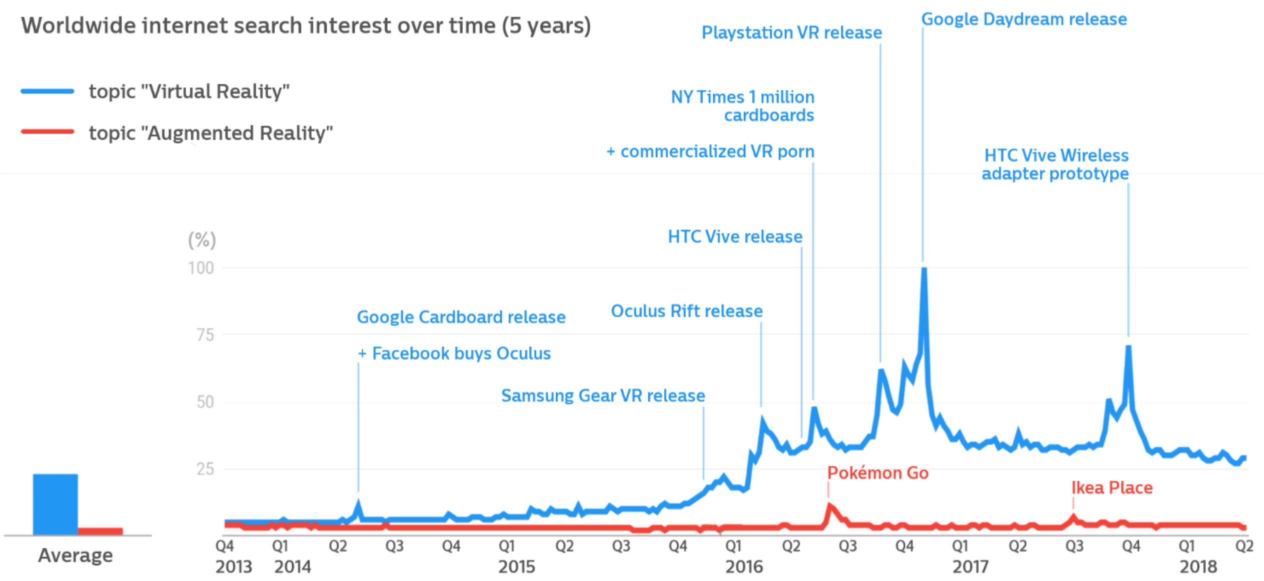

Figure 1: Worldwide internet search interest over time (5 years). Comparison of the topics VR and AR (categorized by Google) enriched with possible impact factors corresponding with peaks (source: own web research). Illustration adapted from Google [Google Trends 2013-2018].

Before the start point of this depiction, no significant peaks exist, the one in Q2/2014 is the first one. In comparison, the internet search frequency of AR has never exceeded the search frequency of VR. The only distinctive peaks might be caused by Pokémon Go (AR game) and Ikea Place (a consumer room planning application, further explained in chapter 2.3.2).

2016 was an outstanding year for VR in terms of popularity – many consumer HMD platforms were successfully released (see blue annotations in Fig. 1). Additionally, 16 million Google Cardboards had been shipped worldwide by July 2016, many of them as part of marketing campaigns for various companies. For instance, the New York Times distributed 1 million units by July 2016 [OneToOne 2016].

The most distinctive peaks occur in Q4/2016 and Q4/2017 – the impact of the pre-Christmas product marketing and sales might be an influence, too. The absolute maximum could be attributed to the influence of the pre-Christmas period in combination with many newly launched platforms, the second highest peak follows in a similar shape and lower amplitude exactly one year thereafter.

Consumer surveys were conducted in Germany [PwC 2016] and China [VRroom 2017], providing insights in awareness and dissemination among consumers in the respective countries and revealing considerable differences between the two markets.

In Germany, in quarter 3 of 2016 (“Q3/2016”), the question, if a given user had heard of or had used VR, was answered as follows (n=1057, age=18+):

- 84.3% had heard of the technology
- 15.7% had already used it (5.7% for non-gaming purposes, 5.5% for gaming purposes, 4.5% for both purposes)

Brand awareness is also inquired by the same study, identifying the best-known HMD hardware devices in Germany at that time (n=166, age=18+):

- 59.2% Samsung Gear VR
- 52.0 % Sony Playstation VR
- 27.2 % Oculus Rift
- 18.8 % HTC Vive

In contrast, Chinese users responded to the question, whether they had already used a VR system, in an increasingly positive tendency over the following timespan:

- 54% in Q2/2016 (n=3200+)
- 73% in Q3/2017 (n=18000+)
- 89% in Q4/2017 (n=6000+)

Brand awareness (of international brands) in China in Q3/2017 (n=6000+):

- 94.6% HTC Vive (1st place)
- 79.4% Sony Playstation VR (2nd place)
- 71.1% Samsung Gear VR (3rd place)
- 67.6% Oculus Rift (5th place)
- 46.5% Google Daydream (8th place)

The Chinese results must be treated with some caution due to the demographic composition: 91% of all participants in Q4/2017 were male and 17.5% stated to work within the VR industry. But the general impression is that in Asia, VR/AR will surpass the *emerging technology* state much faster than in other regions. In 2016, the Chinese government and HTC teamed up to set up a VR/AR fund amounting to $ 158 million. In 2018, a $ 470 million VR theme park called *Oriental Sci-Fi Valley* has been opened. It is reported that the Chinese market has already become rational and there is no doubt of VR/AR readiness for mass adoption. The Asian market prevails on culture, policy and potential buyers, whereas the Western market mainly provides desired content and product and platform developments [Venturebeat 2018].

1.3. VR as an emerging technology

According to the framework *Hype Cycle for Emerging Technologies* by the global research and advisory firm Gartner Inc., both VR and AR have passed the "peak of inflated expectations". That means that they have surpassed the critical "hype" state and are on their way to mainstream adoption. VR is rated the furthest on the scale of maturity (see Fig. 2) and is said to be mature enough for enterprise use [Gartner 2017a].

The technology benchmark (chapter 2) shows that companies already started to use customer-focused VR applications in 2014 but most of them were brought into use after 2017.

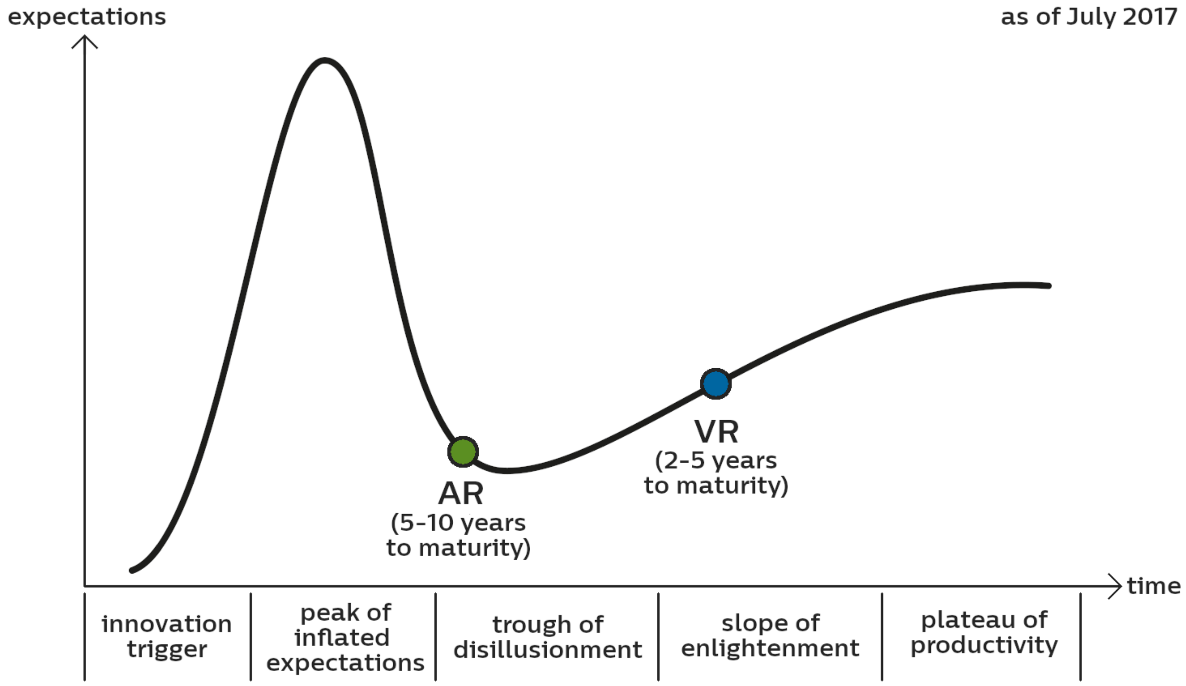

Figure 2: Gartner Hype Cycle for Emerging Technologies 2017. Virtual Reality is rated the most mature technology on its way to mainstream adoption in two to five years, AR follows with a distinct gap with approx. 5-10 years to mainstream adoption [Gartner 2017a].

Even though (mobile) AR is expected to eventually develop considerably more mass appeal than VR [Digi-Capital 2018] (Fig. 3 on the left), some use cases will remain that necessarily require VR. In situations where the target environment is either inaccessible or not yet existent – predominantly in room and factory planning but also in the field of tourism – a VR simulation is the unalterable option.

The biggest advantage of VR planning solutions is to effectively make decisions and operate on physically non-existent realities at true scale and including context [Berg and Vance 2017].

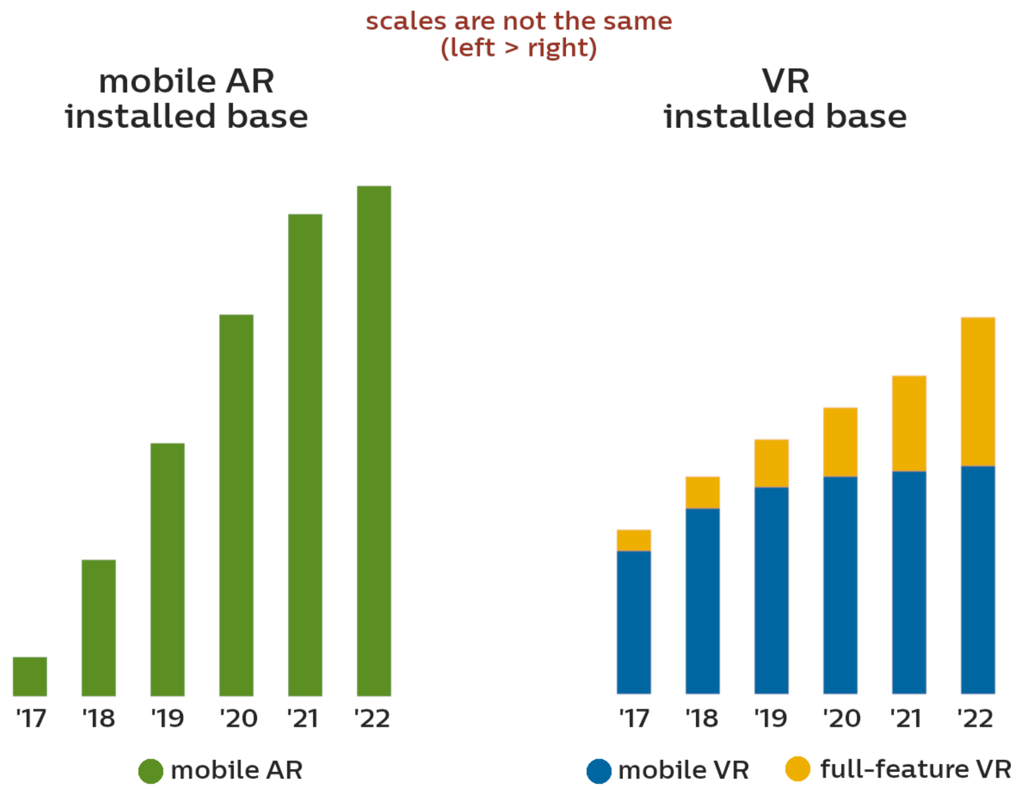

Figure 3: Worldwide AR/VR installed base. On the left: mobile (smartphone-based) AR. On the right: VR (combined). Estimated development of proportions of mixed reality media types by 2022. Own illustration based on literature research [Digi-Capital 2018].

Mobile VR is estimated to make up a solid and constant share of the VR landscape (Fig. 3 on the right) and subsequently will be a well-represented platform in society in the long run. As soon as a technology becomes popular, both business-to-consumer (B2C) and business-to-business (B2B) use cases are more easily accepted. Conceivable B2B use cases of *mobile* VR in particular are expected to be as follows [Zabel and Heisenberg 2017]:

- marketing / promotion / extended brand interaction
- product presentation / visualization
- training / education of employees
- conferencing / collaboration

A German B2B survey (n=343) showed that the actual B2B VR solutions which are already implemented are equally distributed across different industry sectors [Virtual-Reality-Magazin]:

- 15% engineering
- 15% production
- 14% service
- 14% others
- 15% marketing
- 14% sales
- 14% training

1.4. The rapid room planning application

The object of this evaluation is the following mobile VR rapid room planning tool (RRPT) that belongs to the sector of marketing and sales of medical devices. The purpose of this application is to support early stages of a room planning process, where often paper sketches or manual digital sketches serve as only basis for discussion and for drawing of detailed plans in the further course of a project. The idea is to directly sketch ideas of possible room layouts virtually – with actual device models and at true scale. Additional to 2D room layout planning (object arrangement) and 3D verification (visual check) of the setup, the room setup can be experienced in VR, in order to make it more tangible for the customer and to reduce planning errors (e.g. concerning spacings or ceiling height).

Mobile VR with a smartphone as computing platform was chosen because it enables users to quickly and easily set up the tool and because of its compact hardware size. The focus is not set on high-fidelity product rendering, as smartphones cannot render the full CAD detail level in appropriate frame rates.

The use scenario is a quick sketch of room layouts of the room in question during a sales appointment between customer and sales representative. Afterwards, screenshots of the layouts can be exported and serve as enhanced planning basis for following detailed drawings of the room. Another potential use scenario is the product presentation on trade shows, where the RRPT can be useful because of its quick setup and convenient use – but in terms of high-quality rendering in static places, there is another alternative available (see chapter 2.1.).

The RRPT was developed in a master's thesis [Maleta 2018] in collaboration with Philips Healthcare. It uses Google Daydream as HMD hardware in combination with a powerful Android smartphone (e.g. Google Pixel, Samsung Galaxy Note or Galaxy S8) as mobile computing platform.

The workflow starts in 2D mode, where the room form (4 or 6 corners) and dimensions (in meters) can be defined. Afterwards, models can be added to the room from the model catalog, which contains Philips fluoroscopy devices that were created using official CAD models. The user can set definite viewpoints in the 2D planning mode, that function as standing positions in 3D and VR. Subsequently, the user can remain seated or standing and just controls his view through neck movements, whereas the selection of the VR standing position is controlled via a handheld hardware controller.

Figure 4 shows the state of the respective application in a current prototype version (as of June 2018), which is not yet used internally by Philips marketing and sales employees on an official basis. Some aspects of the GUI can and will be further developed (input see chapters 3.4. and 4.4.)

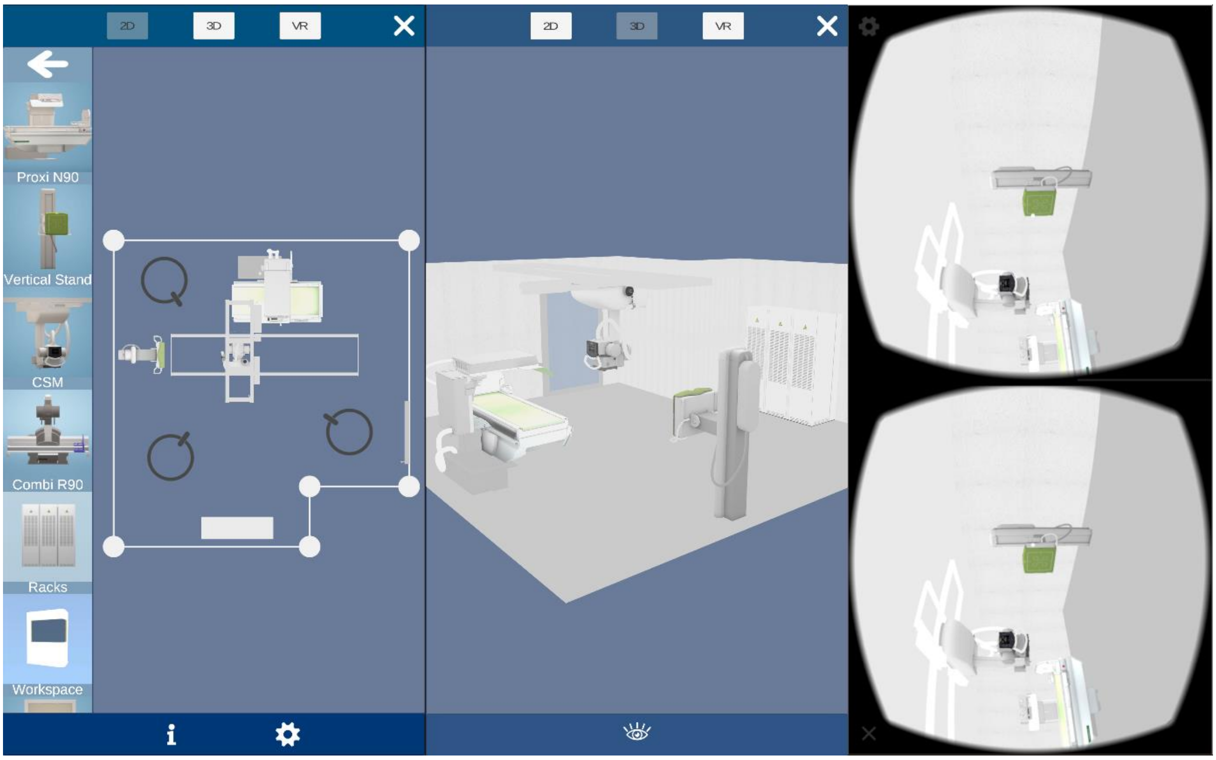

Figure 4: Different modes of the Philips RRPT using mobile VR. On the left: 2D planning with object catalog. In the middle: 3D mode with room visualization from outside perspective. On the right: VR mode in stereoscopic view, to be viewed through HMD for a more realistic impression of the room.

1.5. Possible factors influencing the acceptance and usage of VR applications

For the successful establishment of a customer-focused internal tool that includes VR, it takes more than a useful idea in form of a prototype – some key factors need to be considered to maximize its customer and business impact and the overall acceptance and actual usage.

Through consolidation of literature, analyses and surveys, the following four categories of key factors influencing the general adoption of VR applications were identified. Consequently, the first three aspects (1.5.1. user experience / 1.5.2. customer acceptance / 1.5.3. increase of efficiency) build the foundation and correspond with the evaluation chapters (3./4./5.) as main pillars of this work.

1.5.1. User experience: usability, interaction, look and feel

Usability is a part of system ergonomics, it is defined according to ISO FDIS 9241-210 (revised edition, 2009) as "Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." [Bevan 2009]. Effectiveness of use is defined as task success, efficiency of use is defined as task success per time [Hegner 2003].

This approach is rather goal-oriented and focused on removing obstacles within the workflow to maximize effectiveness and efficiency, also described as "removing friction" (Fig. 5) [Porter 2009].

In contrast, user experience (UX) is not that clearly defined – there are different ways to set the scope of UX [Bevan 2009]:

- As an elaboration of the satisfaction component within usability.
- Distinct from usability.
- As an umbrella term for the totality of the user's perceptions and responses, both subjectively and objectively measured.

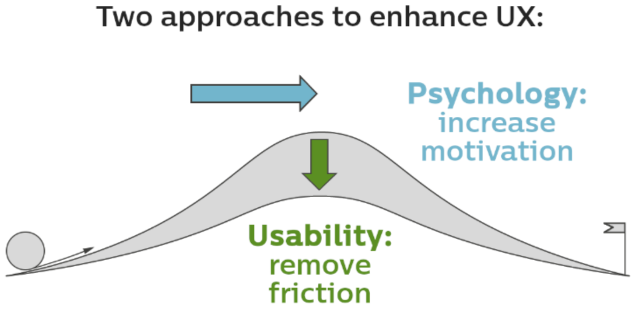

Figure 5: Different approaches for improving UX: Either through usability which ideally removes friction (obstacles) in workflow and interaction – or through psychology, which ideally increases motivation to make users engage more effectively. Source: own illustration, adapted from [Porter 2009].

UX can be seen as a holistic approach for optimizing the user's encounter with and journey through a product or workflow. This cannot exclusively be done by removing obstacles, but likewise through fortifying the psychological incentive, described as "increase motivation" (Fig. 5) [Porter 2009]. So UX measuring methods include hedonic (emotional) as well as pragmatic (task success) goals [Bevan 2009].

UX is expected to be the most important factor or rather the key hurdle to mainstream adoption of immersive computing [Goldman Sachs 2016]. The success of VR systems strongly depends on UX quality [Gartner 2017a] – but currently, many VR systems are failing to keep up with the commonly high UX standards [Bonetti et al. 2018].

The overall UX of a mobile application strongly influences long-term engagement; A study (n=474) examined the determinants of engagement with a mobile (m-commerce) application, noting that "(hedonic) enjoyment influences engagement with a mobile application upon initial adoption, whereas utilitarian (task-related) factors are more influential on engagement after continued retention. The location of mobile application use influences the variables motivating engagement. Following continued retention, engagement influences positive brand attitudes and brand loyalty." [McLean 2018].

The user's impression and mood are additionally influenced by the "look and feel" component: concrete sensory (haptic or visual) experience while using a system. In software artifacts, the graphical user interface (GUI) is the central area of look and feel effects, but also the quality of 3D models matters [Houde and Hill 1997].

In a German B2B survey (n=34) [Zabel and Heisenberg 2017], the vast majority (94%) rates user-friendly handling and navigation as the most important aspect for adoption of VR. A lower percentage (47%) rates aesthetic aspects (high-quality look and feel) as important.

1.5.2. Customer acceptance of HMD

The experience of wearing a HMD may be impaired by bodily discomfort in form of visually induced motion sickness (VIMS) or feelings of claustrophobia. Similar mechanisms (dissonance between perceived movement directions) like in 'traditional' motion sickness due to means of transport play a role [Munafo et al. 2017].

A UK-based consumer survey inquired perceived comfort among VR users: 12% of all users (n=2001, age=18+) reported feelings of sickness and 5% reported incidents of claustrophobia [Foundry 2017].

In an experimental study [Munafo et al. 2017], two different games (neck-controlled VR 3D puzzles) on the same HMD (Oculus Rift) were played by the same 36 participants (18 men, 18 women) for 15 minutes with a sufficient break in between. Standing body sway was measured additionally to verify the subjective reports of VIMS. In the first case, 22% reported VIMS and there were no significant (p=.11) gender differences. After the second game, 56% reported VIMS and a distinct gender difference was noted: 78% of the female users reported VIMS, but only 33% of the male users. These results indicate that women are more susceptible to motion sickness in some situations – whereas another study (n=32) [Treleaven et al. 2015] does not support these claims: at a VIMS rate of 28% after neck-controlled VR, there were no age and gender correlations (p=.05).

Furthermore, comfort may be compromised also by social inhibitions of being reluctant to wear a HMD in public or in conversational situations, especially if people have never experienced VR before. This isolation through the HMD is a circumstance that cannot be eradicated as a fundamental difficulty while using VR – by definition the display blocks the user's entire field of view, therefore it fully shields the user from the visual outside world stimuli that could at least occasionally be interesting for interaction (see Fig. 6).

Figure 6: Mark Zuckerberg at the Samsung session at the Mobile World Congress 2016 [Infinityleap 2016].

It is reported that in China, the social stigma of wearing a HMD in public is much less developed than it is in Europe and America [Venturebeat 2018].

1.5.3. Increase of efficiency or enhancement of existing workflows

Since objects can be experienced in realistic proportions in VR, there is great potential in improving the efficiency of existing use cases that rely on spatial perception. In B2C context, this prominently concerns online shopping of furniture, where the market volume is estimated to € 160.4 billion [Statista 2016]. In B2B context, the possibility of efficiency improvement applies likewise: increased quality in engineering and design as well as better productivity and efficiency (both for engineering and product presentation) are considered possible key advantages of B2B VR applications in a German survey (n=1057) [PwC 2016]. Furthermore, there are two different categories of use cases: visual and functional ones, resulting in different modelling and rendering requirements. The fidelity of a simulation only depends on the questions posed – perfect rendering is not always required for decision making. For B2B applications the enhancement of functional simulation (reconstruction/optimization) is more important than the total immersion [Berg and Vance 2017].

The circumstance of missing evidence for increased productivity or return-on-invest is a common hurdle for adaption of B2B VR solutions, 47% of respondents in a German survey (n=36) rated it as a critical factor, whereas the circumstance of missing customer workflows for integration was rated as critical by only 19% [Zabel and Heisenberg 2017].

1.5.4. Other consumer market factors: price, content, platforms

HMD hardware is still expensive (low-end VR: ca. € 20-70, mobile VR: ca. € 100-200, full-feature VR: ca. € 300-800 (all prices without smartphone/PC) [Pagel and Hauck 2017a]), though it is believed that HMD hardware will undergo the same price decline as seen on PCs and smartphones, with prices falling by 5-10% annually [Goldman Sachs 2016]. The maximum price that UK consumers are willing to spend for a HMD in general averages at £ 134 (=ca. € 150) [Foundry 2017]. In Germany, that maximum price also averages at € 153 [Zabel and Heisenberg 2017].

The existence of suitable consumer content, which could boost HMD hardware sales is a chicken-egg-problem: demand and creation depend on each other and won't be resourced if there is no reasonable chance of success. Another problem are missing standards and interoperability, interaction design is often implemented differently between hardware and software components. This could result in further fragmentation of the platform landscape, as long as no "hero device" will distinguish itself [Zabel and Heisenberg 2017].

Consequently, people must be animated – or at least not discouraged – to use VR technology. Once VR has reached the state of mass adoption (if a critical mass of users worldwide is familiar with the technology and uses it on a daily basis), B2B usage of VR applications might be positively affected in terms of usability and customer acceptance.

1.6. Structure outline of this work: central driving factors

As stated before, the first three factors (UX, customer acceptance and increased efficiency) represent the fundamental aspects and driving factors for a successful establishment of VR in the case of intended B2B use. To examine the extent of presence of these criteria in the case of the RRPT application, these aspects are evaluated in separate approaches.

The underlying structure of this work bases on reflections on literature that outlines the current state of VR or estimates possible future scenarios, from which four fields of evaluation are deduced (see Fig. 7).

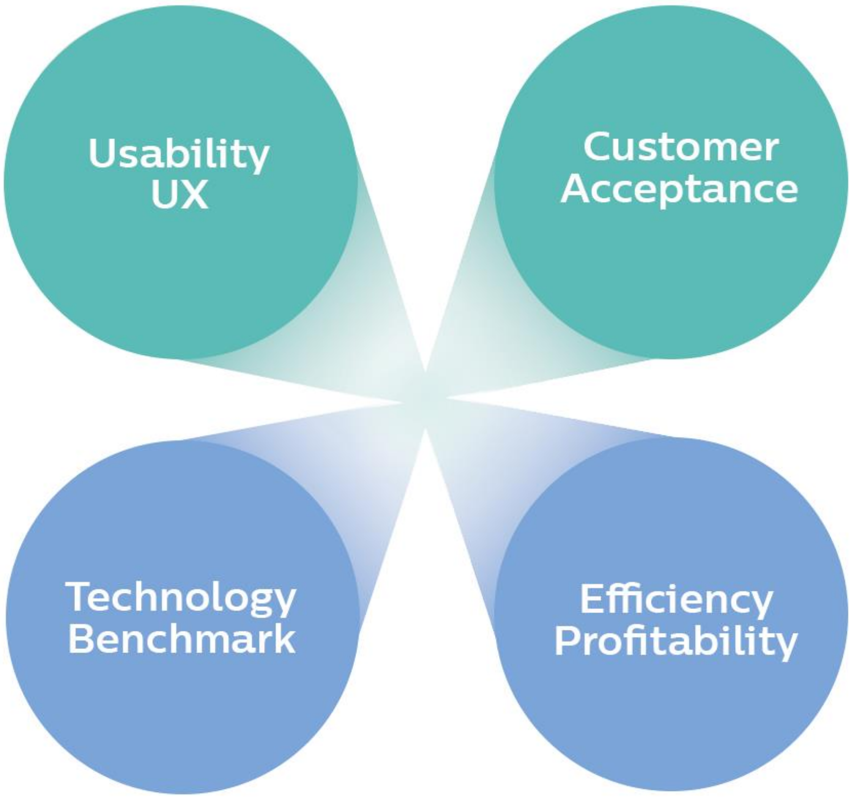

Figure 7: Central driving factors for the successful adoption of a VR solution in B2B context. The 4 categories constitute the main pillars of this work, represented by the following evaluation chapters. Source: own illustration.

The upper two aspects (user experience and customer acceptance) can be tested in a small-scale study with a set of appropriate test users and customers. These studies were included as an integral part of this work, whereas the evaluation of profitability through an internal long-term evaluation was not included in the scope of this work.

The evaluation of these four aspects constitutes the content of the following main chapters:

- The technology benchmark (chapter 2) of XR applications in the field of marketing and sales of high involvement goods is set, which mainly intends to reveal existent and successfully maintained customer-focused VR applications. It outlines different approaches that various companies have taken und points out specialties of particular applications. Additionally, it relates the use case of product visualization of medical imaging devices and how some findings could be considered as ideas for features in the further development of VR visualization applications.

- Profitability through increased efficiency (chapter 3) is investigated through literature research and examination of included expert opinions. Furthermore, the chapter discusses the steps that would need to be taken in order to internally assess profitability and the possible reduction of planning iterations through the RRPT.

- Usability and UX (chapter 4) of the RRPT is evaluated in observed user tests and an associated Philips Healthcare employee survey. The chapter summarizes the test results and findings that lead to further recommendations in a compact overview. Additionally, it outlines different UX factors that influence continued usage of mobile applications, which is a goal for the application of a RRPT.

- Customer acceptance (chapter 5) is evaluated in a survey with healthcare professionals following a personal demonstration of the application and the direct experience of the VR visualization. The improvement of spatial imagination in comparison to traditional product presentation media is investigated. The chapter summarizes the survey results and customer suggestions in a compact overview. It focuses on literature that reports an improvement of spatial imagination through general imagery and especially through VR visualization, as well as and a subsequent positive effect on decision confidence and purchase intention.

Following the suggestions and ideas for further development that resulted from the employee and customer surveys, the creation of further content for the application is described (chapter 6) – most prominently an interaction overview for the RRPT, which can be implemented as an in-app help and initial tutorial section.

The summary (chapter 7) offers a complete overview of all insights and outlines three possible concepts for further development of the RRPT.

2. Benchmark: state of the art of XR applications in marketing and sales of high involvement goods

Involvement is one of the individual determinants influencing purchase behavior and purchase intention. High involvement purchases are characterized by intensive information research and careful assessment of alternatives before the actual transaction. High-tech goods (solutions using most advanced technology available) or high-touch goods (products with a sensory and very close user relationship) are often the center of such purchase decisions. High involvement purchases are associated with inherently high risks (financial, functional, social, psychological, physical) that the buyer seeks to minimize [Pepels 2018]. In the case of room planning, these risks mostly concern financial risks and functional risks or feasibility issues (room dimensions or interdependency of objects).

An international B2B study has shown that product-related marketing material, which conveys clear information leads to increased satisfaction among all sales channel members and to higher sales [Schmitz 2006].

Visual marketing material traditionally includes paper-based brochures and digital 2D product presentation images and videos. But an increasing number of companies is starting to use XR (VR and AR) media for marketing and sales purposes – in the following subchapters, an overview of successfully implemented and used XR (most prominently VR, some AR) applications in various high involvement contexts is shown, relating to the use case of high involvement room planning, which is subject to the later evaluation chapters (4./5.).

2.1. Philips Healthcare

In 2018, the RRPT application (including 2D, 3D and mobile VR visualization) was developed, which has already been described in chapter 1.4. and is subject to the later evaluation chapters (4./5.).

In 2017, a full-feature VR application was developed, using HTC Vive as HMD hardware combined with a high-performance laptop as computing platform and including a similar model catalog as the RRPT does. Its main purpose is to digitally exercise realistic workflows on the fluoroscopy devices. This can be done with customers, for product presentation purposes for instance on trade shows, as well as with healthcare professionals for training purposes.

Figure 8 shows the final state of the full-feature VR application. The application supports two different visual styles: a normal white wall style and a “wellness” style, which includes wooden or colored wall textures and a gray floor. Customer feedback shows that people like and tend to select the “wellness” style much more frequently. All models have a very high level of detail and support realistic device control via virtual buttons that can be accessed through the handheld controllers, which are represented by white hand models in VR mode (see Fig. 8 at the bottom).

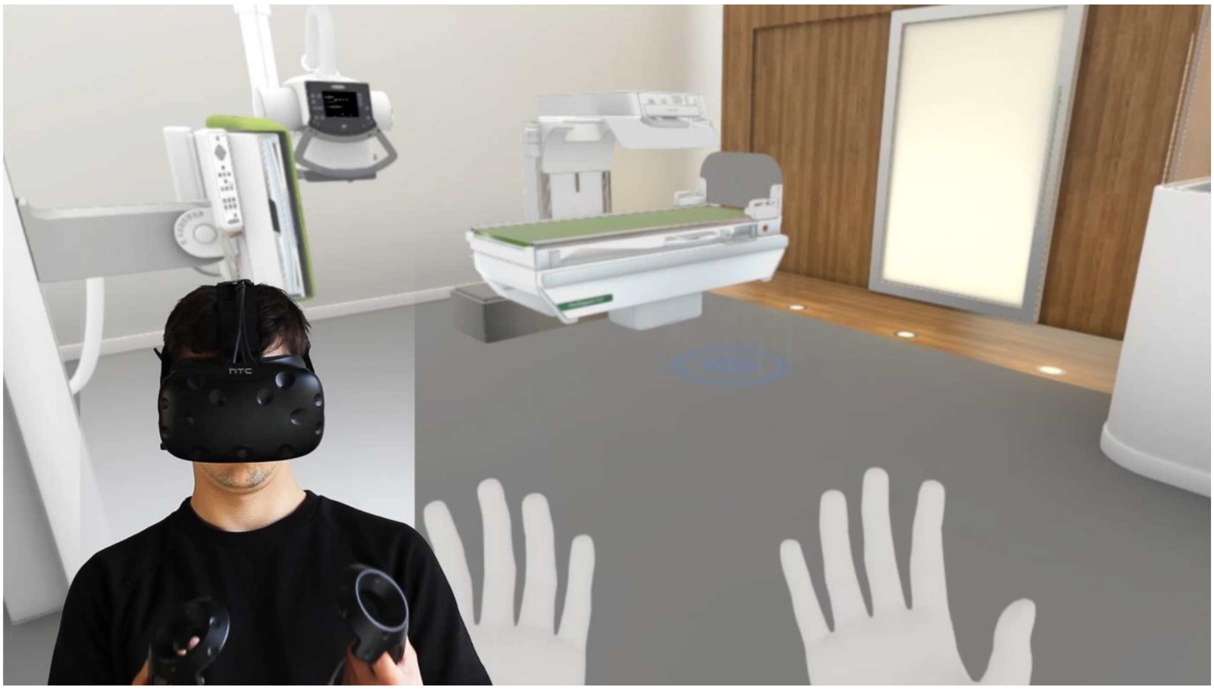

Figure 8: Screenshot of a promotion video for the HTC Vive-based Philips VR application. It supports high-fidelity rendering as well as interaction with the products via two hand controllers. Body movements are directly translated into the virtual environment [Philips 2017].

A disadvantage of the full-feature VR system is the extensive setup – laptop, controllers and optical position tracking systems are contained in large and heavy storing boxes and need to be arranged and connected. Additionally, a suitable free floor space of approximately 4x3 meters is necessary to be able to walk around. The whole setup can be done in about 15 minutes.

These efforts might not be appropriate for a short first assessment of room layout options within a limited time – some sales appointments last for an hour or less and include more agenda points than just this room layout sketching. As a more efficient and lightweight tool to support the virtual assessment of layout options, the RRPT (described in chapter 1.4.) represents an alternative solution for such situations.

2.2. Competitors in medical imaging systems sector

Worldwide revenues in the sector of medical imaging devices of the top ten companies that develop, manufacture and market medical imaging systems have been determined and compiled to a statistic report [Statista 2018a] as follows.

Actual revenue in 2016 and projected revenue in 2022 are included. The market leaders are:

- Siemens (2016: $ 10.1 billion / 2022: $ 11.4 billion)
- General Electric (2016: $ 8.4 billion / 2022: $ 10.2 billion)
- Philips (2016: $ 7.4 billion / 2022: $ 9.0 billion)

Other competitors follow with a distinct gap, the strongest three are:

- Canon (2022: $ 4.1 billion)
- Fujifilm (2016: $ 2.3 billion / 2022: $ 2.7 billion)
- Carestream (2016: $ 1.3 billion / 2022: $ 1.6 billion)

Consequently, the web presence of the other competitors was examined for signs of VR application usage, prominently the other two market leaders.

Siemens Healthineers offers a full-feature VR visualization mode (see Fig. 9, HMD hardware not known) as an integral part of a complete room planning project with Facility Design Services that are conducted in many extensive and challenging cases. An ambient VR simulation is presented alongside general functional 2D/3D/4D visualization and workflow optimization in special planning cases. Less tangible factors like atmosphere, light, space and privacy are made perceptible in VR [Siemens Healthineers 2018].

Figure 9: Web presence illustration of Siemens Healthineers Facility Design Services including 3D/4D visualization of anticipated room setup in full-feature VR as an integral part of a complete room planning process [Siemens Healthineers 2018].

It is not described whether VR is only used to present product renderings that are passively experienced by customers or if it also serves as a workflow or room planning feasibility tool to enable customers to actively engage with products.

Other competitors in the field of medical imaging systems (especially GE Healthcare) were not found to present usage or development of other comparable VR room planning solutions.

2.3. Other comparable high involvement sectors

As defined beforehand, high involvement implies extensive information research and careful assessment of possibilities and options before finalizing an investment purchase. This is especially relevant in the field of room planning, both for business (e.g. factories) and consumer room planning – the following examples illustrate existing approaches.

2.3.1. B2B factory planning

Software determines the performance of a plant and differentiation to competitors will only be possible through software, as product life cycles get shorter. Ease of use and customer support in factory planning and after-sales-service will be decisive criteria when it comes to buying factory solutions [Schnaithmann 2018].

The German engineering company Schnaithmann Maschinenbau GmbH counts on VR planning software “Cross Connected” by Rüdenauer 3D Technology (R3DT), which is a spin-off from the *Karlsruher Institut für Technologie* (KIT). The software was released 2017, it uses HTC Vive as HMD hardware and Leap Motion (camera-based) for hand gesture tracking.

In early conception stages of a planning project, the customer is able to experience ‘his’ factory setup in VR. CAD models can be directly uploaded into an associated web tool, which functions as an object catalog in subsequent VR simulations of the planned factory setup. Feasibility checks and ergonomic examination of workflows are possible in this true-scale virtual planning model. It can be used for training purposes, too.

At the automatization trade show *Automatica 2018* in Munich, two more companies have presented their VR factory planning software tools: *Comau* and *LEWA Attendorn*, which are described in the following.

Comau S.p.A. – an Italian robotics company – uses VR to plan factory setups and enhance inspection and predictive maintenance of existing factory setups through a digital twin simulation. This means that the actual production machinery setup is virtually modeled in 3D and accordingly displayed in VR. In the presented case this has been applied to an automotive production plant – the door assembly of the Maserati Levante. All actual functionalities can be virtually accessed, relevant data of the production plant is displayed on a virtual handheld tablet in VR. Additionally, machine status and potential incidents are visually highlighted on the models.

The respective virtual environment was set up in collaboration with FlexSim, the general VR application was developed in collaboration with Autodesk and Continuous Composites. It uses Oculus Rift as HMD hardware and a high-performance laptop as computing platform. The user can interact with the virtual machines in the plant and change standing position via two handheld wireless controllers. A specialty is the interaction with natural finger gestures (pointing with extended index finger), which adds a realistic aspect to the experience. The tool is expected to increase productivity and decrease costs for predictive maintenance of respective production plants [Comau 2018].

Another company that uses VR for factory planning is LEWA Attendorn GmbH. Within a personal presentation at Automatica 2018 it was possible to experience the VR application, though it is not presented anywhere on the internet. It helps customers envision their anticipated factory environment and experience the actual CAD models at true scale and detail level. It is already being used in ongoing factory planning projects.

The environment setup is done in 2D and 3D visualization. Object interaction and change of standing position (“teleportation”) is possible via one handheld wireless controller. A specialty of this application is the adaptive level of detail of objects, which depends on the need to be shown in full detail. This is made possible through the implementation of a special algorithm (not known whether it affects rendering processes or model simplification). If inspected at close range, small machine parts and filigree robotic components appear very detailed and lifelike. Yet, very large environments can be modeled in one simulation. Still, a normal high-performance PC can maintain the rendering work. HTC Vive is used as HMD hardware and it is planned to use the newly announced wireless adapter for the HTC Vive as well.

2.3.2. B2C room planning

In the field of consumer (domestic) room planning some planning solutions that include VR or AR exist: *Lowe's Holoroom*, *Roomle* and *Ikea Place*. They are outlined in the following.

Lowe's – a US home improvement retail company – has established an in-store workflow that helps customers envision their anticipated room layouts and possible furniture setups. Their application is called *Holoroom* and was launched in 2014. Its workflow includes 2D, 3D and PC-based VR. While in store, a stationary tablet (see Fig. 10) serves as user interface, where room layouts can be manipulated. They are forwarded to a PC to be rendered and displayed on a VR headset. The customer experiences 'his' room layout in VR but does not have any handheld controlling devices, changes are applied by the employee. The application also includes the opportunity to save the particular room layout sketch for later. This enables customers to additionally experience it on a low-end VR (cardboard) HMD at home for re-assessment [Lowe's Innovation Labs 2014].

Figure 10: Screenshot of a video presenting the application Lowe's Holoroom. A simple room layout with a cupboard and a window is shown. In the upper left corner, the 2D top view of the room is displayed, the standing position of the user is indicated through a cone-shaped viewpoint icon, which happens to be very similar to the considerations in chapter 6.1. [Lowe's Innovation Labs 2014].

In 2016, Roomle – a consumer room planning and arrangement multi-platform application – was launched. It can be accessed on smartphone, tablet and PC, using the same data of one personal account. It features an extensive object catalog with customizable items by many different brands, including IKEA, HAY, USM and Vitra.

Customers can set up room layouts in 2D or 3D (see Fig. 11) on their own. Additionally, they can view single furniture objects via real-time overlay in mobile AR visualization or they can experience whole room layouts via virtual walkthroughs in mobile VR visualization [Roomle 2016].

Figure 11: Different modalities featured in the multi-platform domestic room planning application Roomle. On the left: 2D and 3D visualization of the same floor layout – 2D is rendered simpler that 3D. On the right: VR visualization mode, to be experienced in Google Cardboard [Roomle 2016].

In 2017, IKEA launched a mobile AR domestic room planning application for smartphone and tablet, named *IKEA Place*. The customer can select furniture items and place them into his immediate environment through AR that overlays his smartphone camera view. Afterwards, screenshots can be saved and exported to social platforms.

Although the application does not feature 2D, 3D or VR, it is relevant for the use case of high involvement room planning; IKEA is one of the biggest furniture retailers in Germany, with a revenue of € 4 billion in 2013 (the second-biggest furniture retailer made € 2 billion) [Statista 2018b]. Additionally, AR is estimated to reach a huge user base (see chapter 1.3.). Consequently, a lot of people are already familiarized with the concept of XR room planning and the associated virtual experience of not yet existent environments.

2.3.3. B2C automotive

In terms of customer-focused high-fidelity rendering on full-feature VR systems, Audi first announced a stationary full-feature VR solution at the trade show CES Las Vegas in 2016. HTC Vive is used as HMD hardware and a high-performance PC as rendering device. The application conveys lifelike impressions of the products (i.e. car models) that are fully customizable. The manipulation of models is done by an employee and the VR visualization can be experienced by the customer, who controls his view and standing position through natural walking due to the visual tracking of the HMD across the room. At the same time, the employee and other users that are not wearing HMDs can follow the active user's VR view on a large TV screen. This is useful for bigger groups of customers or even for customers who are reluctant to wear a HMD. A specialty of this application is the adaptive rendering of inside components: When the user's viewpoint gets close to a model surface or looks inside a model, the surface becomes transparent and the inner parts that are normally not shown become visible [Audi 2016].

Figure 12: Audi full-feature VR application. The user experiences a fully configurable high-fidelity virtual model of a product, including all setups and accessories that are available. It helps making decisions that always involve some kind of visual stimulus [Audi 2016].

Among the top 20 automotive brands with the highest market share in Germany, 18 of them have at least one XR product visualization application for marketing and sales. VR and AR technology is used to deliver a more experiental way of advertising to the customer, although in many cases, an additional support application is needed to view the XR content. Five of the automotive XR smartphone applications reach more than 50,000 installations. Through using these XR media tools, the visual imagination of the product (i.e. car) is increased in comparison to traditional 2D or 3D advertising media. Additionally, these applications generate higher emotional binding of the customer to the product [Pagel and Hauck 2017b].

2.4. Benchmark summary and discussion

The examination of existing XR applications in marketing and sales of high involvement goods reveals a multitude of different approaches that have been successfully established in different sectors and for different use cases. Figure 13 gives an overview of the results, horizontally showing sectors and companies that use XR for product visualization and vertically the different modalities that are comprised by the respective applications.

Benchmark overview: XR applications in marketing and sales of high involvement goods

	B2B						B2C			
→ x: sector company	medical imaging systems			factory planning			auto-motive	room planning		
↓ y: modality	Philips RRPT	Philips Vive	Siemens	Schnaith-mann	Comau	LEWA	(various)	Lowe's	Roomle	IKEA
2D / 3D	●		●	●	●	●		●	●	
full-feature VR		●	●	●	●	●	●			
mobile VR	●						●			
low-end VR							●	●	●	
mobile AR							●		●	●

Figure 13: Benchmark overview, horizontally split into B2B and B2C und subsequently into the use cases room planning for medical imaging systems, factory planning, automotive marketing and domestic room planning. The modalities and technologies that are featured by the presented VR applications are indicated vertically. Own illustration based on literature and web research.

All applications have own specialties (concepts or implementations), from which some of them are crucial for high involvement room planning and could be considered for the XR visualization of medical imaging devices.

- Siemens uses full-feature VR to create an immersive atmospheric experience of a full room layout, focusing on subtle aspects like ambient light, space and privacy in an anticipated environment.

- Schnaithmann focuses on VR simulations that support effective and efficient customer feedback cycles in planning projects and that can be created using an easily accessible web tool.

- Comau maintains a digital twin solution with VR experience to enhance service, maintenance and monitoring of devices.

- LEWA Attendorn has implemented a sophisticated rendering or model simplification algorithm that allows a very high level of detail when needed, even with large room setups.

- Audi makes products tangible in full-feature VR and has a special rendering logic that selectively reveals inner parts at close inspection.

- Lowe's focuses on a customer-friendly workflow that involves 2D, 3D and VR in-store room planning and the opportunity to review the layout sketches on a Cardboard-based VR HMD later at home.

- Roomle offers a multi-platform solution that enables the user to plan on a bigger screen (e.g. laptop) and view the room layout in mobile VR using a smartphone.

- IKEA uses AR for integration of digital product models into the user's immediate environment, which is well suited while situated in the actual room that the planning is being made for.

For instance, the possibility for the customer to take 'his' room layout home and re-experience and re-assess it in another place and time is an interesting concept that could be considered in the further development of the mobile VR RRPT. Through a room layout saving functionality the raw data could be stored and exported directly instead of indirectly through screenshots. The customer would physically receive a branded Cardboard-based HMD and digitally receive their respective room layout datasets. This could give people who did not attend the customer consulting meeting the opportunity to experience and assess the room layout sketches as well. The model fidelity would not pose a difficulty for low-end VR visualization, because the models are already optimized for smartphones, which do not have the same rendering performance as PCs. However, the high-quality brand experience could be impaired by the usage of rather cheap Cardboard-based HMDs.

Additionally, the visualization of ambient lighting in rooms that is available as an optional feature could be considered in the further development of the RRPT to allow the customer to experience a ambient lighting solution already at an early stage of the room planning project.

Furthermore, advanced rendering or model simplification algorithms could be investigated to facilitate future creation of new models for smartphone-based VR applications from original CAD device models.

3. Considerations on profitability by reduction of planning iterations

As stated in chapter 1.4.1., the improvement of efficiency is a main factor for the application of B2B VR solutions. This can be translated into an increase in overall profitability. In the present case of the evaluated RRPT, this increase in profitability is most likely to be generated through the reduction of pre-sale planning iterations between customer, sales representative and drawing office, to establish a more elaborated and convenient foundation for understanding spatial challenges already early in the course of a project. But however, the amount of potentially savable pre-sale planning iterations in real room planning projects remains a variable to be determined.

3.1. Method: theoretical inquiry of expert opinions

Within the scope of this work, it was not possible to complete an initially planned direct evaluation of planning iterations in real ongoing medical room planning projects. Instead, a literature review of expert opinions is used to inquire potential profitability, analyzing ratings in comparable fields of B2B VR room planning. The expert opinions are related to customer-focused solutions in engineering and thus, effects of VR usage on customer-focused iteration and decision processes can be compared to the use case of medical room planning.

3.2. Results

According to a US-based B2B study that focuses on VR applications within the design process, companies are widely convinced that VR simulation brings a financial benefit. Measuring return-on-invest is worthwhile: "As finding issues early in design is a core goal of VR, it is also important to calculate cost avoidance. At Lockheed Martin Space Systems the impact of specific findings is estimated. 'This is where it gets a little tricky,' the laboratory manager explains, 'there is always the question of - well would I have found that issue if I didn't use VR?' Usage records together with prototype cost data were used to justify upgrade costs to multiple facility technologies at General Motors. Showing, with records, that VR has saved both time and money is a proven method of increasing confidence in the technology." [Berg and Vance 2017]

Internally, increasing efficiency and speeding up decisions are the most important criteria for B2B VR usage, whereas externally, the heightened use value for customers is important [Pagel and Hauck 2017c].

Volker Sieber, development manager at Schnaithmann Maschinenbau GmbH, is confident that factory planning in VR together with customers can help avoiding a lot of extra iterations needed until the final plan is ready to be implemented. The usage of virtual prototypes is a key condition for agile project management. Additionally, project costs are reduced by elimination of physical prototypes. As an effect, feedback cycles with customers accelerate and increase their effectiveness – through early visualization and virtual trials in construction feasibility and ergonomics customers obtain a better understanding and hence, less planning iterations are needed [Schnaithmann 2018], which results in lower project costs.

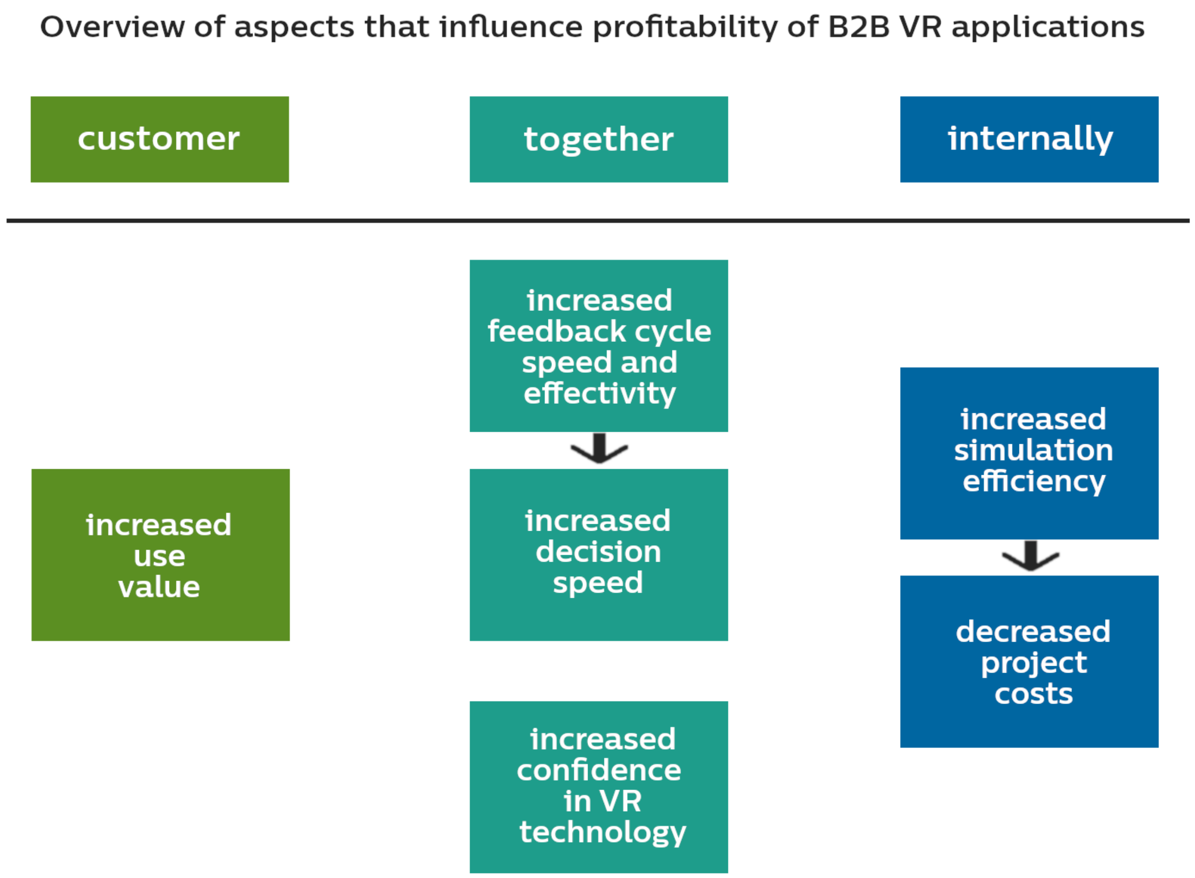

Figure 14: Overview of aspects that influence profitability of B2B VR applications, horizontally split into the different parties involved: customer, together (between customer and company) and internally (company). Own illustration of literature research.

3.3. Discussion

The results indicate potential for increasing the overall profitability of medical room planning processes through a RRPT solution – most prominently through the ability of VR simulations to accelerate customer feedback cycles and increase their effectivity, which results in increased decision speed.

Furthermore, project costs associated with the drawing of detailed plans might decrease due to a more convenient data foundation (i.e. digitally exported room layouts designed in the RRPT instead of manual drawings).

Customers might profit through increased use value, given the case that the RRPT generates a better visual foundation for understanding, in order to draw attention to spatial challenges already early in the course of a room planning project. Additionally, the ability to experience ambient factors such as lighting could represent a heightened use value for the customer.

Still, the empirical assessment of the possible reduction of planning iterations remains a challenge. A long-term evaluation with a duration of six to twelve months could reveal the overall effect of the usage of a RRPT, as room planning projects may extend over several months with several feedback and decision cycles.

An employee (i.e. sales representative) or better, a group of employees using a RRPT would have to be set up to ensure reliability of results. A central documentation of usage would have to be set up for all employees, where a project identifier (e.g. Salesforce-ID or similar IDs) would be tracked together with and details of the RRPT usage at customer appointments (modes used, customer engagement and – if applicable – customer feedback). This documentation would allow the counting of the number of pre-sale iterations within one project through the project identifier.

All results would have to be compared to planning projects of similar complexity, either from the past or from parallel projects, to determine the difference between RRPT including VR visualization and traditional approaches. This might turn out to remain difficult – even with many data collected – as there is no general 'reference room planning case' to be quantified. The scope of projects can vary greatly, and subsequently, the percentage of potentially savable iterations could also vary depending on the different levels of organizational challenges within a project and room-related constraints that need to be taken into account for the continued drawings.

4. Evaluation of usability and UX

As described in chapter 1.5.1., usability is a part of system ergonomics and comprises effectiveness of use, efficiency of use and satisfaction of use. In user-centered design, the concept of measuring usability is a commonly used practice in the assessments of newly developed systems or system prototypes (both hardware and software) [Hegner 2003].

In the general medical context, usability is especially critical, either because it could affect the treatment of patients or – as in the present case of the RRPT – it is crucial for efficient procedures within a healthcare facility. The availability of healthcare professionals (doctors, nurses, assistants) for extensive customer consulting appointments is limited and thus, a tool supporting product presentation and room planning purposes must be unobstructedly usable by potential users.

In a normal RRPT workflow (defined in the following chapter) the 2D mode is primarily operated by the employee (i.e. sales representative), whereas the 3D and VR mode can be operated both by the customer (i.e. healthcare professional) and the employee. However, the room layout creation in 2D mode makes up most of the actions taken within a normal workflow. Subsequently, the usability of a whole workflow mode with employees, but most prominently the 2D mode, is analyzed in the following.

4.1. Method: observed user test and survey among Philips Healthcare employees

A usability test simulates a practical scenario in which a qualified test user (similar to intended users) faces a series of pre-defined tasks to be completed with the artifact (i.e. system or application) in question. The general purpose of a test is to find errors and difficulties – a usability test focuses on identifying common mistakes in interaction, task completion and understanding. The purpose is to quantify the extent of usability (effectiveness, efficiency and satisfaction, see chapter 1.4.1.) on a measuring scale. All incidents and outcomes within the specified test scope are documented, including measuring time needed to complete certain tasks. The simplest form for documentation is a paper-based observer sheet that is filled out by a particular person that is given the observer role. Additionally, a moderator guides the test person through the test, not revealing any critical information concerning the workflow but being able to intervene if the user cannot proceed on his own. Normally, the moderator lets the test participant act freely and only gives a brief introduction to the system before the user begins performing the actual tasks [Hegner 2003].

In the case of this work, the number of available assistants to help conducting the user tests and the allocated time frame did not allow the assignment of a single role to a single person. This means that there were no separate observers whose only task would be the documentation of observed incidents and user performance. Instead, a single person would occupy the role of the moderator as well as the role of the observer (in the following only called "observer"). This circumstance required the preparation of a combined document for both roles (see appendix, chapter 9.2.1.) with check boxes for the tasks as well as the coherent moderation hints in order to make sure that the moderation always follows the same scheme to allow direct comparability of the results. The test protocol includes a complete rapid room planning workflow (planned total time: max. 10 minutes) with following pre-defined tasks to be completed:

- 2D mode: configure an exemplary room with 6 corners in settings menu and change dimensions (primarily length and width), either by dragging corners in 2D or by numeric input in settings menu
- 2D mode: open side bar catalog, add 4 models to the room (2 imaging devices, generator racks and door) and at least 3 viewpoints, then select, move and rotate several objects (via 1-finger-tap, 1-finger-drag and 2-finger-twist gestures)
- 3D mode: find 3D mode, look around the room (orbit and zoom view via 1-finger-drag and 2-finger-pinch gestures), toggle viewpoints via touch interaction in the bottom bar
- VR mode: find VR mode, mount smartphone into HMD, put on HMD, activate handheld controller, look around in VR, toggle viewpoints via handheld controller

To assess effectiveness of use, task success in each individual task was measured on a 4-point scale (0-3):

- 3 equals complete success (user completes task quickly and on his own with full understanding of procedure)
- 2 means minor difficulties (user completes task mostly on his own, only abstract help is given, no details like the position of a critical area to proceed with workflow are revealed by observer)
- 1 means major difficulties (user completes task partly on his own, receives detailed help and explanations concerning the workflow)
- 0 equals complete failure (user gives up or gets stuck, task must be completed by observer in order to proceed with workflow)

The time in 2D mode was measured with the stopwatch functionality of the observer's smartphone, following respective cues to start and stop in the test protocol.

Additionally, all obstacles or difficulties in understanding that the test participants encountered and that were either expressed verbally by the test user or that observed in user behavior were noted as comments to the respective tasks in the intended fields on the observer sheet.

In total, 29 user tests were conducted with Philips Healthcare employees from various business units (foremost marketing and sales, but also service, informatics, documentation and trainees) as test participants in following places:

- 11 in Rosenheim, Germany in connection to a regular sales meeting
- 7 in Leipzig, Germany during the *99. Deutscher Röntgenkongress*
- 11 in Hamburg, Germany at the Philips headquarter

In Rosenheim, three observers conducted the user tests, whereas in Leipzig and Hamburg, they were conducted by a single observer. The tests in Hamburg did not include the Google Daydream hand controller due to incompatibility of the available smartphone model (Motorola Z2).

In addition to the observed user tests, a survey was conducted among the test participants who were asked to fill out a questionnaire (see appendix, chapter 9.2.1.) directly after the task performance session. The questionnaire includes questions to the main topics of task adequacy, expectation conformity, controllability, self-descriptiveness, error tolerance, learning suitability and as a last section, special questions concerning VR. Every question is represented in two contrary extreme (positive and negative) statements. The test participant was asked to rate on a 6-point scale (---/--/-/+/++/+++), to which extent he/she would agree to which of these two statements (positive statement = +++ and negative statement = ---). In some cases, questionnaires were filled out without taking part in an observed user test, mostly due to available time frames. In total, 34 employee questionnaires were completed.

All results involving any kind of measuring scale were at first visualized in histograms that show the relative frequencies of each rating to each question. In other words, how often all respondents have given a certain rating in a particular question (for raw data histograms see chapter 9.2.2.).

Subsequently, all histograms were summarized in a boxplot visualization. This visualization technique involves splitting the distribution of a ranked dataset into *quantiles* (n subsets) – in this case *quartiles* (4 subsets). This means that a whole data set is divided into equidistant subsets whose boundaries are the three quartile points. The first quartile point splits off the lowest 25% of data (“1st quartile”) from the highest 75%, the second point (“median”) cuts a data set in half and the third quartile point splits off the highest 25% ("3rd quartile") of data from the lowest 75%. The specialty of this data arrangement technique is that the median splits the number of entries in the data set into two equal halves and consequently is more robust against extreme values than the arithmetic mean value (sum of all values divided by number of addends).

Additionally, the minimum and maximum of a data set are indicated through *whiskers*, which are fine lines at the sides of each horizontal set of quartiles. All statistics visualization techniques were done in Microsoft Excel. Boxplots were created using a combined graph representation (stacked bar chart and single value chart). Furthermore, the graphs were enriched with the arithmetic mean value of that particular question, to allow a comparison between median and mean value – a great discrepancy marks the presence of strong extreme values.

Additionally, a *two-sided t-test for known variances* [Hain], also called *independent* or *unrelated two-sample t-test* was performed in Microsoft Excel with the raw data for each individual question of all employee questionnaires. A t-test is a statistical hypothesis test to determine if two data sets are significantly different from each other. The assumption that variances between the two subsets are produced by the *normal* (*Gaussian) distribution* and that both subsets originate in the same population constitutes the *null hypothesis*. The *alternative hypothesis* is that the subsets originate in different populations. The *significance level* (α) indicates a possible error of the first kind. This means α is the probability of mistakenly rejecting the null hypothesis if the null hypothesis is true. The significance level was set to 0.05 (5%), which results in *a confidence level* of 0.95 (95%). In the analysis, the *critical t-value* and the *actual t-value* are calculated. If the actual t-value is smaller than the critical one, the null hypothesis can be accepted.

In this case, the purpose of the t-test is to examine if the rating given by respondents in the survey depends on either age or customer proximity (which equals the alternative hypothesis). The age classes were categorized as follows: the class "young" refers to 20-40 and the class "old" to 40-65. Customer proximity was grouped via the job or department descriptions given by the respondents – the class "near" includes key account managers, marketing, sales, customer service and project managers, the class "far" includes informatics, documentation, business development and trainees. Only subjects with valid data were included in the analysis. All results were recorded anonymously, only relevant and essential data was collected – all declarations of personal data were voluntary.

4.2. Results

The results of all 29 user tests were included in the data analysis. All users were able to complete the workflow and in only two cases, a single task success was rated with 0. The median values of the task scores are at 3 in seven of the total nine tasks and are 2 in two of the total nine tasks. The high rate of 3 as median indicates that few help was needed in most cases, which can be translated into good overall usability.

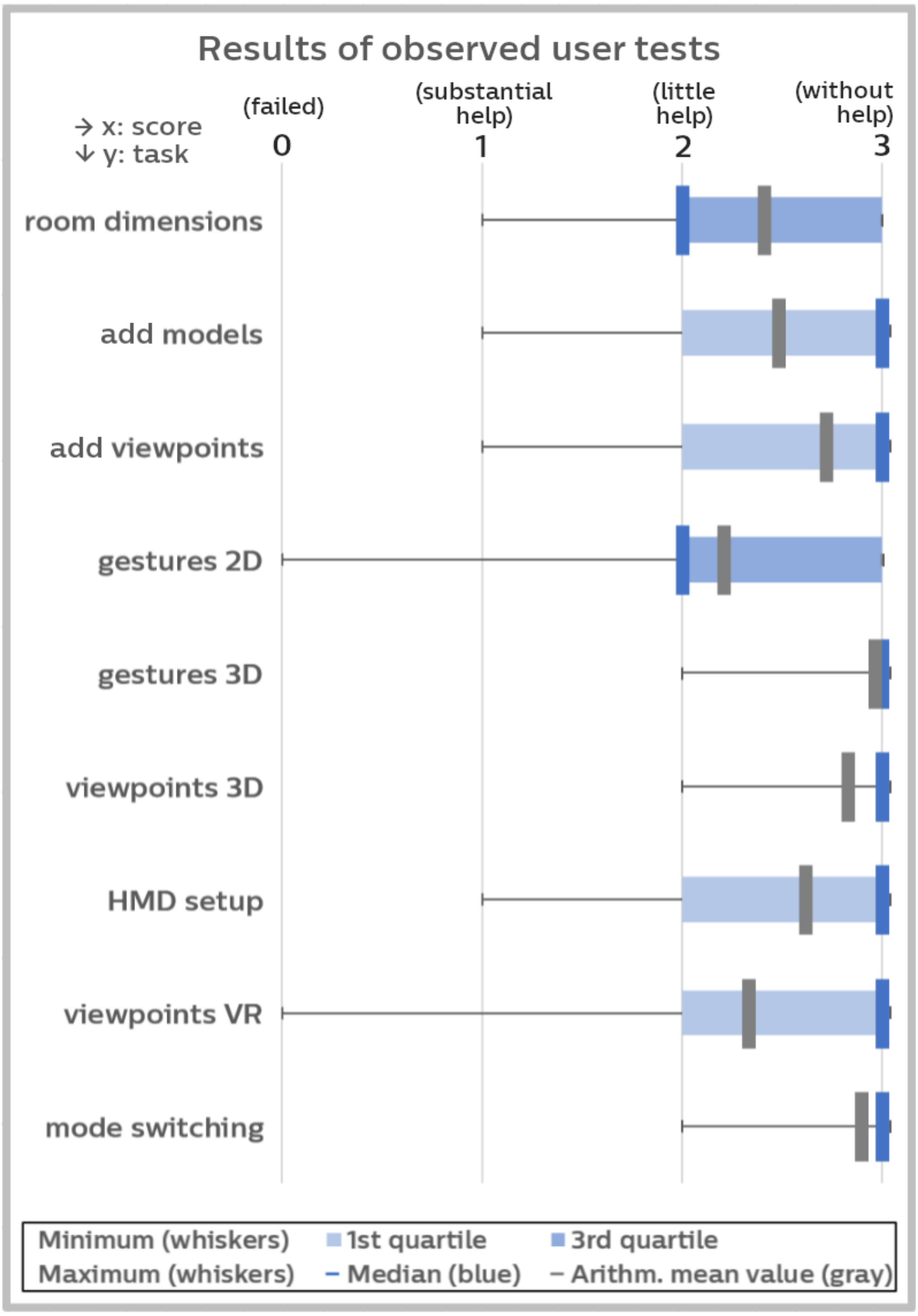

Figure 15: Boxplot visualization of observed user test results. The statistics show how much help was needed by test participants complete all tasks defined in the test protocol. 3 is the best achievable score. A right-skewed distribution can be observed, with the majority of scores at 2 or 3, which indicates that in very few cases, substantial help was needed. The time needed in 2D mode averages at about 5.03 minutes with a variance of 1.6 minutes.

The arithmetic mean value of the time needed for the creation and manipulation of room layouts in 2D mode was 5.03 minutes with a variance of 1.6 minutes. The minimum was 2.73 minutes and the maximum 9 minutes.

Figure 15 shows the boxplot visualization of the results of observed user tests. In some rows (tasks) the impression can arise that some quartiles are missing (because the median is displayed over them) since only integral numbers are possible as scores.

As stated in the previous chapter, the median (blue bars in boxplot) splits the distribution of a ranked dataset into halves, whereas the arithmetic mean value (gray bars in boxplot) divides all values by the number of addends. Discrepancies indicate the presence of extreme values in the direction of the mean value in respect to the median.

In this case of the 0-3 scale, noting the median values points out critical tasks more reliably: Only “room dimensions” and “gestures 2D” have median values at 2. This narrows the focus on these categories, but definitive obstacles that test participants encountered cannot be found via the medians.

Notes on the observer sheets were condensed in order to determine the frequency of issues. The most frequent obstacles were as follows:

- Touch zones: Test users tried to manipulate objects wanting to use full-screen touch gestures, which is not possible with this prototype.

- Room shape: The selection (4 or 6 corners) in the settings menu was unclear, as it is not indicated with a check mark or highlighting. Additionally, the numerical entry fields for room dimensions were often not expected be editable, because they have gray font color.

- Viewpoint icon: The shape (see chapter 6.1.) was often interpreted as a power button symbol due to its circular shape intersected by a line.

- Side bar behavior: Many users tried to close the side bar by tapping next to it, which is not possible in this version. Additionally, many participants expected the model catalog to have a *drag and drop logic*, which is not the case.

- VR mode: The only obstacle outside of 2D mode was the middle button labelled with “-“ on the handheld wireless controller, which closes the VR mode, which some test users did not expect.

A full list of all usability findings can be found in the appendix (chapter 9.1.) together with a complete list of model requests and feature ideas, that were recorded from both employees and customers. Model requests and feature ideas are summarized in the results of customer acceptance (chapter 5.2.).

All 34 received UX questionnaires were included in the analysis. The overall results of the employee survey are visualized in a boxplot depiction (see Fig. 16). The median of two of the total 15 questions is at 4 (+), the median of six questions is at 5 (++) and the median of four question is at 6 (+++), which can be translated into high overall employee acceptance of the RRPT.

The aspect of gesture sensitivity received the lowest rating, the median is at 4 (-) (mean value = 3.59, variance = 2.18). This is consistent with the usability findings, as many participants struggled with 2D gestures.

VR pre-experience (see Fig. 16, last row) is rated with a median of 4 (+) (mean value = 3.36, variance = 2.43). In comparison to the results of the customer survey (chapter 5.2.) this represents a high level of VR experience.

Many employees expressed their wish for a further developed version, both showing their sympathy for this concept of a VR application supporting the use case of room layout sketching and wanting to influence the functionalities featured in future versions. It was stated frequently that the 3D mode is more helpful than the VR mode, e.g. in a group of ten people if only one HMD is available: The possibility of parallel viewing and collective discussion on a 3D visualization of a room layout was preferred over the option of sequential viewing through a HMD, because only one person at a time can experience the visualization. It was stated that parallel streaming of the same view on both the HMD and a beamer would be the ideal functionality setup.

Additionally, the hypothesis that survey results are independent of customer proximity and age were tested, using a two-sided t-test as described in the previous chapter. As a result of the t-test, this hypothesis could be accepted – the variances of the subsets are small enough for the respective two subsets to be included in the same population, there are no significant differences. For the complete list of critical t-values, see chapter 9.2.3. and 9.2.4. in the appendix.

Within the subset split by customer proximity, the question whose results were located closest to the critical t-value was “functionality overview” with $t=1.515$ and $t_{critical}=2.068$ and higher ratings among the group “customer-near”. Within the subset split by age, the question whose results were located closest to the critical t-value was “would use in work routine” with $t=-1.549$ and $t_{critical}=2.068$ and higher ratings among the group “old”.

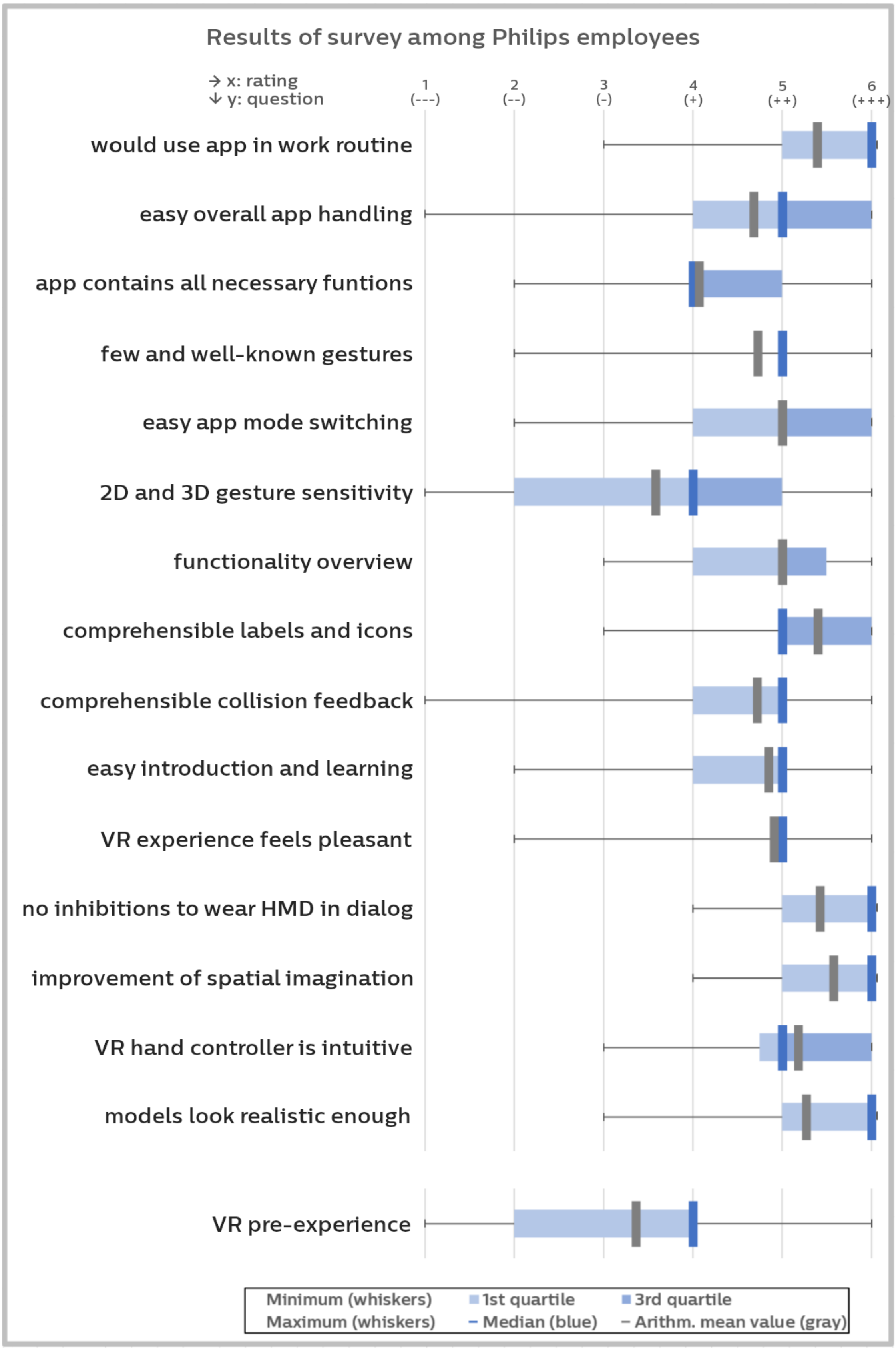

Figure 16: Results of survey among Philips employees, showing the ratings (x-axis) to the questions (y-axis) in the questionnaire that were usually filled out by employees after an observed user test. All questions were represented in contrary statements where the user could agree to the negative by choosing 1 (---) or agreeing to the positive by choosing 6 (+++) or an intermediary state. In this graph, the positive statement is displayed to represent a question, but the results concern both statements.

4.3. Discussion

The average time needed to complete the 2D workflow (five minutes, whole workflow: 10 minutes) is a very promising finding regarding the work routine suitability in tight time schedules of appointments.

The absolute comparability of the usability test score (0-3) can be argued, as it is categorized by the observer according to the performance of the user and amount of help needed. This may result in slightly different categorizations ("is it a 1 or 2?") with different observers. However, general scale precision proved to be helpful for these tests, where a limited set of tasks was performed with participants having varying professions and IT knowledge and additionally, within a rather short time frame, which does not allow very detailed categorization of help needed.

The efficiency of use could be calculated by dividing the total task success score (sum of task scores) in certain tasks by the time needed for the respective tasks. In the case of this usability study, the only reasonable time parameter to be measured is the amount of time needed in the 2D mode - as in 3D and VR mode, users can easily spend a lot of time, independent of the extent of usability. Consequently, 2D efficiency could have been assessed, but the potential results of this parameter were inconclusive, as in some tests, the scope did not contain viewpoint tasks due to mentioned incompatibility issues.

The combined boxplot visualization can point out the most prominent obstacles ("show stoppers") that appeared within the tested workflow scope in one single view. However, the ability to reveal these critical task sections depends crucially on the partitioning of tasks: if one task is too macroscopically defined that it includes one difficult and one easy task, the results of that task might not be as meaningful as if these two parts would have been split into two separate tasks.

Observed user tests are an important foundation to a generally conducted usability assessment (which may include expert ratings and other methods as well). Data gained from actual and potential users is helpful and valuable and can serve as primary influence on profound design decisions in software design and development.

The additional questionnaire adds a user-centered subjective component to UX analysis as the statements are directly reported by the respective user that also performed an observed user test. It is interesting that sometimes task performance and user rating can differ greatly in both ways (bad task performance and good rating or vice versa). Another idea, which was not included within the scope of this work is the method of examining possible correlation or anticorrelation between task performance and user rating with a larger sample size.

A crucial parameter of software use – especially of mobile applications – is continued usage. A long-term study (n=271) identified the dependency between continued application usage and (positive or negative) emotions that derive from the act of using the application. Positive emotions are elicited by experiential and social factors of the application usage. On the other side, negative emotions tend to be influenced by instrumental benefits (effectiveness and efficiency) of the application and are responsible for the disconfirmation of expectances, which is a driving factor for usage discontinuance. Both the increase of positive emotions and the decrease of negative emotions lead to increased long-term engagement with the mobile application [Ding and Chai 2015].

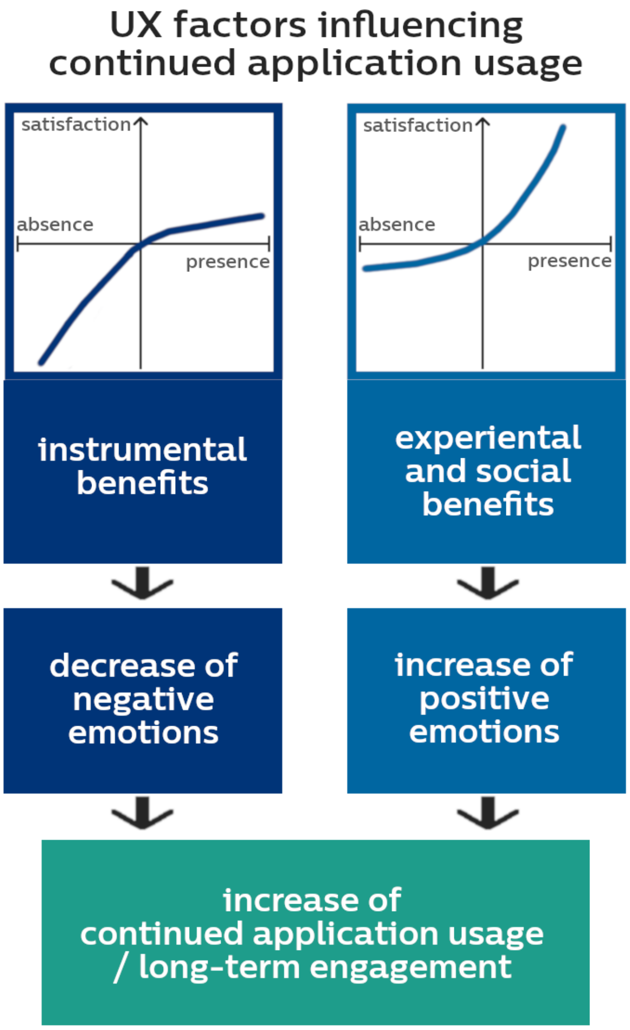

Figure 17: UX factors influencing continued application usage. Instrumental benefits (left) lead to decreased negative emotions, whereas experiential and social benefits (right) lead to increased positive emotions. Both positively affect continued application usage. Own illustration of literature research [Ding and Chai 2015].

In other words, the satisfaction component of usability prominently determines the circumstance of continued usage. The different categories of characteristics and their effects can be compared to the factors of the KANO model of customer satisfaction [Ullah and Tamaki 2011]:

- Instrumental benefits are similar to "must-be quality" factors in the KANO model, they represent basic needs that are expected by the customer/user, their absence leads to decrease of satisfaction (see Fig. 17, left graph).
- Experiental and social factors can be compared to attraction factors or "delighters" in the KANO model, their presence leads to increase of satisfaction (see Fig. 17, right graph).

In the present case of the RRPT, the instrumental benefits are represented by efficient and effective 2D sketching of layout and interdependency / feasibility checks in 3D and VR, whereas the ability to view non-existent room layout at true scale is clearly an experiental benefit. Social benefits could be constituted by the ability to discuss room layouts on the same basis (3D or VR mode) within a group of colleagues.

The consensus remains that usability is main criterion for user satisfaction [Zabel and Heisenberg 2017]. According to internal insights at Philips Healthcare, the first few minutes of application usage decide whether an application is accepted or rejected by the user. Once the prominent workflow obstacles are eliminated through further development of the RRPT, many users that now reach a medium score in observed user tests are more likely to reach higher scores in the future. Also, the reported user acceptance is likely to increase.

A central insight arose during personal talks with the participants after observed user tests and during filling out the survey: Splitting between status quo (i.e. prototype) and general concept (the idea behind it, a possible future state of the application) would have been useful. If a given group of respondents is 100% contra status quo but 100% pro general concept, in a survey, where questions equally concerning the two different states of the application are mixed up in one questionnaire, the result would be 50% pro application, what would lead to an inaccuracy of statements that could be deduced.

Even if some users report to prefer the 3D visualization mode over the VR visualization mode for efficient planning in groups, all modes (2D/3D/VR) have their benefit and right to exist. Especially VR is essential to be represented within the application implicitly making people (both customers and employees) familiar with the technology of VR, which is – as stated in chapter 1.2. and 1.3. – an emerging technology that is not yet widely disseminated in society but has great potential in room planning use cases as well as in training context [Zabel and Heisenberg 2017]. There are future plans and successful first steps for VR training applications (both in medical and engineer context), one example is a practical test of a VR simulator for special brain surgeries at the department of neurosurgery at the Kepler university hospital in Linz, Austria. Test participants with an average of 14 years of clinical experience tried and rated the application: 89% stated better anatomical understanding after simulator use and 94% want this procedure to be included within the education of surgeons [Gmeiner et al. 2018].

4.4. Recommendations for further development

The most prominent usability findings (described in chapter 4.2.) led to tangible suggestions how the concerned aspects could be improved during further development:

- Touch zones of objects (especially small objects) could either be extended to the full extent of the screen except head and bottom bar, or another logic could be implemented; All touch zones must have minimal absolute sizes (e.g. a minimal size of 150x150 pixels or better, 1x1 cm, so that this parameter is equivalent on various devices).

- The viewpoint icon implemented in the application could be changed, the design approach taken in chapter 6.1. could constitute an appropriate alternative.

- The settings menu could be re-designed, with room shape selection highlighted more clearly (e.g. through a checkmark) and the numerical input fields in normal font color. Additionally, the "X" button could be changed to "OK" or "apply".

- The catalog icon "+" and other GUI icons could be re-implemented, using solid and coherent icon resources from the official *Philips Asset Library* (https://www.assetlibrary.philips.com/).

- Sidebar behavior could be re-designed, including a drag and drop logic and the option to tap next to it in order to close it. If a drag and drop logic would interfere with other logic, a mechanic of always placing new objects mid-screen could be implemented, which would solve the problem of objects not being directly visible after being placed. Wall-dependent objects (e.g. door) could be placed in the closest spot to the visible area instead of a default position.

5. Evaluation of customer acceptance and improvement of spatial imagination

Another important influencing factor for the successful adaption and actual usage of a B2B VR application is customer acceptance: Only if the customers are willing to try the new concept of wearing a HMD in a dialog situation to experience virtual models and simulations, the application can deliver its full potential. Once customers seriously engage with the possibilities that emerge from using VR visualization, their spatial imagination of the room layout and understanding of device proportions in room context might improve. To test this hypothesis, a VR demonstration and corresponding survey was conducted among healthcare professionals.

5.1. Method: RRPT demonstration and survey among healthcare professionals

19 participants took part in the procedure of demonstration and survey, representing potential customers. 16 of them were medical-technical radiology assistants (MTRAs) and three medical doctors. It was conducted at the booth of Philips Healthcare at the German radiology congress *99. Deutscher Röntgenkongress* that took place in Leipzig in May 2018.

A full workflow demonstration of the Philips RRPT (see chapter 4.1.) was given to the participants. Room layouts were created and manipulated by the evaluation conductor. Customers experienced 3D mode and VR mode through the Google Daydream HMD, including the ability to control the viewpoints via the handheld wireless controller.

After experiencing the VR visualization, they were invited to fill out a questionnaire concerning functionalities, completeness of the model catalog, expectation conformity, controllability and as a last section, special questions concerning VR. Each question is represented in two contrary statements and participants were asked to give subjective responses to rate on a 6-point scale (---/--/-/+/++/+++), to which extent he/she would agree to which of these two statements (positive statement = +++ and negative statement = ---). The customer survey questionnaire bases on the employee survey questionnaire to ensure maximal comparability. It was simplified through leaving out some statements that are not applicable.

Additionally, a separate section concerning the effect of VR visualization on spatial imagination in comparison to traditional product presentation media (2D pictures, 2D videos and real product presentation) was added to the questionnaire, in order to test the hypothesis described in chapter 5.

This special section allows ratings on a 5-point scale (--/-/0/+/++), where "--" means VR has greatly worsened the customer's spatial imagination in comparison to the respective traditional media and "++" means that VR has greatly improved the customer's spatial imagination in comparison to the respective traditional media. However, a neutral statement had to be possible in case that the customer's spatial imagination had not been affected by VR, this is the reason for the usage of a 5-point scale.

After the survey, results were visualized in histograms (for raw data histograms see chapter 9.3.2.). Subsequently, all histograms were summarized in a boxplot visualization (in the same manner as described in chapter 4.1.) using a combined graph in Microsoft Excel (see Fig. 18).

5.2. Results

All 19 received questionnaires were included in the analysis. Two of the eleven app-rating questions show a median at 4 (+), eight of them show a median at 5 (++) and one ("would appreciate in work routine") has its median at 6 (+++). This can be translated into overall high acceptance of the RRPT.

Especially the concept of VR visualization receives very good ratings, all medians of questions rating the qualities of the VR mode are at 5 (++).

The lowest ratings are given to the questions concerning the completeness of model catalog and application functionalities: The responses to the question "the model catalog contains all necessary models" show a median at 4 (-) (mean value = 3.63, variance = 2.58). The responses to the question "the application contains all necessary functions for room planning" also show a median at 4(-) (mean value = 4.05, variance = 1.61).

The VR pre-experience (see Fig. 18, last row) is reported much lower than in the employee survey: Respondents in the group of customers rate this question with a median of 1 (---) (mean value = 1.58, variance = 1.37).

In personal talks subsequent to the workflow demonstration and completion of the questionnaire, healthcare professionals expressed their high acceptance for the concept that underlies the development of the RRPT and for the mobile VR visualization. Extensive feedback and ideas were expressed and collected concerning the status quo of model catalogue and features. The following issues are a combined presentation of results from both the employee and the healthcare professional evaluation (complete list in chapter 9.1.).

- Most prominently, a model of a standardized patient bed was addressed, as this is a central object in all radiology workflows. According to many MTRAs, the maneuvering of a bed poses a common challenge in medical imaging rooms.

- Multiple and wider doors were requested, as the implemented standard door could not satisfy all needs for a realistic setup.

- The wish for a workflow animation (across the whole room) or for animated movable device parts was expressed, as the static models could not satisfy all demands for an appealing product experience.

- A saving functionality was requested frequently, on the one side because after closing the RRPT smartphone application – intentional or unintentional ("crash") – the room layout was gone. This would turn out to be even more inconvenient in cases where definite layouts had been assembled carefully and would constitute a foundation for a real room planning project. On the other side, a saving functionality would enable users to open room layouts independent of devices.

- The wish for measurements of spacings between objects, displayed in 2D and 3D mode if needed by the user, was expressed. As an interesting and possibly helpful feature, some participants imagined the possibility to toggle a measuring mode on a certain object via handheld controller interaction in VR mode, but not permanently active.

- Atmospheric aspects like configurable ambient wall or ceiling lighting and customizable wall textures were expressed.

Many healthcare professionals reported that being able to use the VR mode quickly and while sitting or standing is very convenient – even in confined spaces like a congress booth. Customers stated that this circumstance would animate them to try the RRPT workflow in real a customer consulting or sales appointment as well. Even participants who were reluctant to try it at first eventually experienced the VR mode, because it is easily accessible and does not involve any extensive hardware preparations and only a short software preparation (room layout setup) that can be done by an employee who is already familiar with the application.

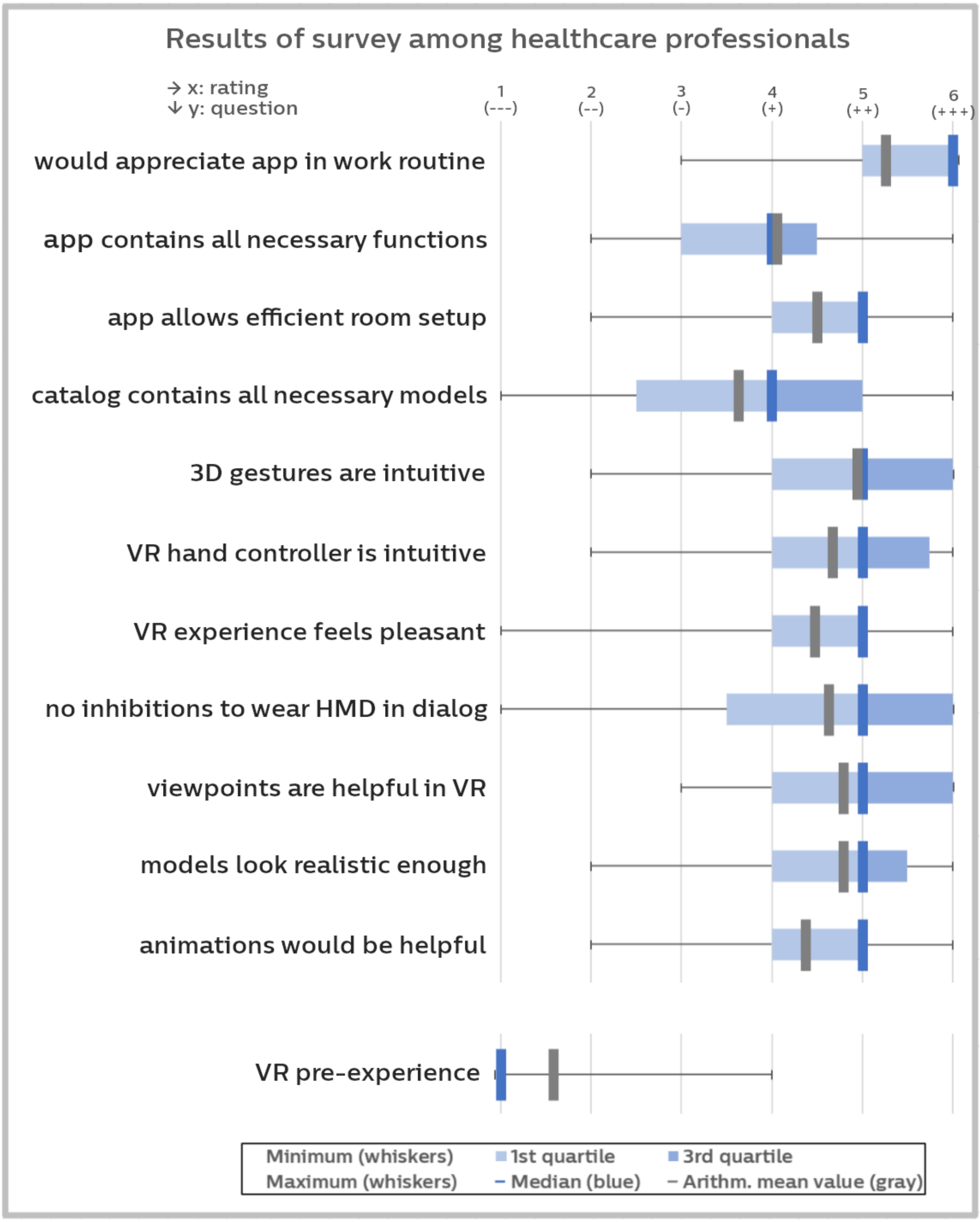

Figure 18: Boxplot visualization of healthcare professionals survey results, showing the ratings (x-axis) to the questions (y-axis) in the respective questionnaire. All questions were represented in contrary statements where the customer could agree to the negative by choosing 1 (---) or agreeing to the positive by choosing 6 (+++) or an intermediary state. In this graph, the positive statement is displayed to represent a question, but the results concern both statements.

The separate questionnaire section concerning the improvement of spatial imagination of devices proportions in comparison to traditional product presentation media (i.e. 2D pictures and videos that are shown in traditional marketing and sales approaches) revealed the delivered the following results (see Fig. 19): Versus static 2D product pictures (both photography and renderings), the effect of VR visualization was rated with a median at "better" (+). In comparison to animated product videos (for advertising and information purposes), the effect of VR is also rated with a median at "better" (+) but with a lower arithmetic mean value. In comparison to a real (immediate and haptic) product presentation, the effect of VR product presentation is rated as "has not affected my spatial imagination of device proportions" (0). The overall rating conveyed by the respective mean values is positive, indicating that most respondents think that the use of VR visualization improves the spatial imagination of device proportions in the anticipated environment.

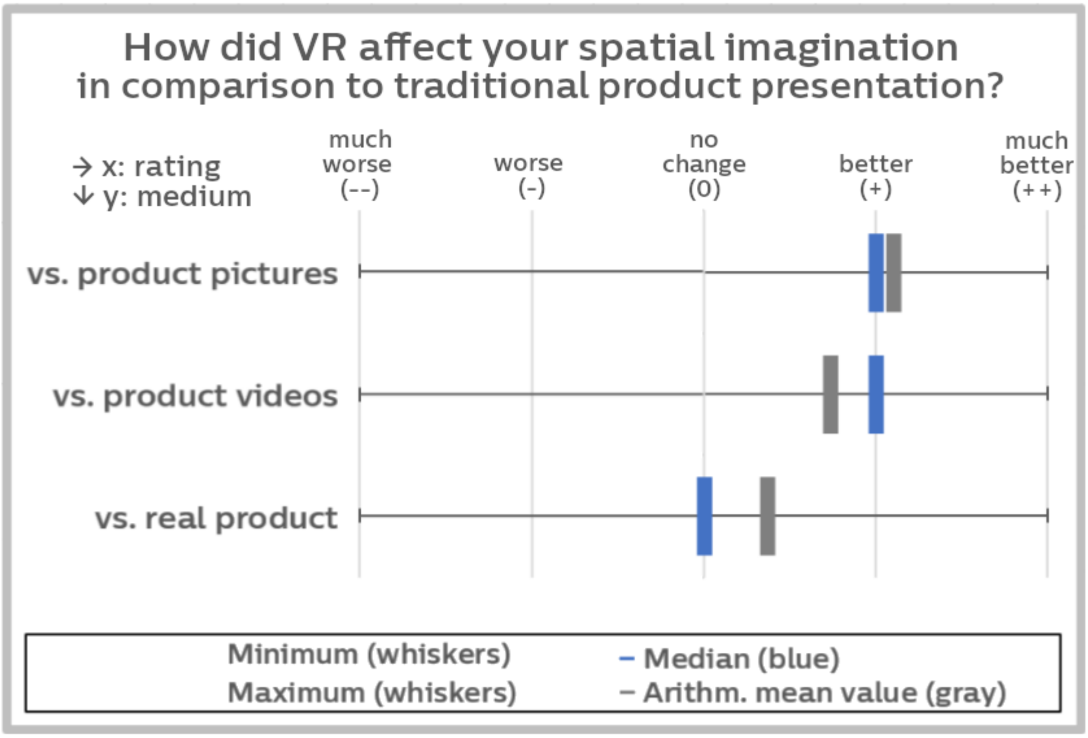

Figure 19: Boxplot visualization of separate section in the healthcare professionals survey concerning the effect of VR on spatial imagination in comparison to traditional product presentation media. Versus 2D pictures and videos, a clear positive rating on the effect of VR can be noted.

5.3. Discussion

The participants in the evaluation with healthcare professionals were mostly (84%) MTRAs. According to internal experience at Philips Healthcare, this professional group is well suited for the analysis of customer acceptance towards a customer-focused tool, as MTRAs may have high decisional power in hospitals regarding imaging devices and room setups.

The importance of the findings concerning the improvement of spatial imagination for the use case of medical room planning gets evident when looking at related literature – they are consistent with findings of four different studies examining the effects of general visual imagery and VR visualization in particular:

Both discursive and imagery processes can be used for problem framing, risk assessment and attribute evaluation. The way how a problem is presented (verbally or visually) can have dramatic impact on solution strategies and time needed to complete problem framing, risk assessment and attribute evaluation (faster with imagery) [Simon and Hayes 1976].

This means that in the case of medical room planning, customer consulting approaches involving visual imaging might be advantageous over mere verbal presentation and discussion in terms of effectivity and efficiency of problem framing, risk assessment and product attribute evaluation.

A study examining the role of visual imagery reports a reversed relation between number of product attributes visualized within a decision process and the reported complexity of the decision. In other words, the more attributes a customer knows and sees through product imagery, the easier he reports his choice to be. Additionally, the study finds that imagining outcomes (visually or verbally) increases their perceived likelihood by making the outcomes more salient and easier to recall (visually more than verbally). There is a positive relation between elaborated imagery and enhanced purchase desire, which results in reduced time intervals between purchase consideration and actual purchase [Price and Macinnis 1987].

Persuasive communication strategies need to focus on helping audiences imagine the positive sensory and emotional experiences deriving from the possession and usage of the product, especially with high-cost and high-risk products [Price and Macinnis 1987]. These findings directly apply to medical room planning, as it involves persuasive communication strategies for products with a very high level of involvement and may face long time intervals until final purchase decisions.

Figure 20 shows a combined overview of the findings of these two studies that focus on the usage of general visual imagery strategies.

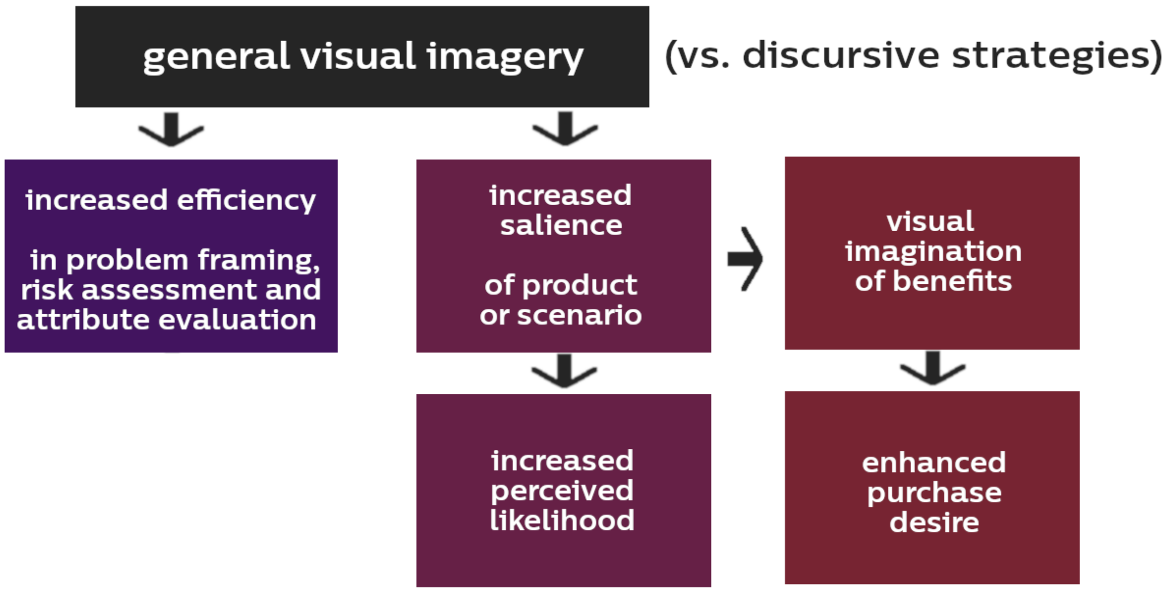

Figure 20: Overview of the effects of the usage of visual imagery in comparison to discursive strategies. Ultimately, perceived likelihood of a certain scenario and purchase desire are positively affected. Own illustration of the findings of two different experimental studies [Simon and Hayes 1976] and [Price and Macinnis 1987].

A study focusing especially on VR room planning finds that object inspection and learning of product information and features (especially concerning the interdependency of objects in room planning situations) is significantly improved through virtual assessment in VR, thus increasing decision confidence and purchase intention [Yoon et al. 2008].

The visual modality (2D/3D/VR) in which the product is presented does matter, too: an experimental study showed that the product presentation modality (2D-pictures/3D-rotation/VR-mirror) positively affects the sense of local presence (telepresence), which is significantly higher for VR. The effect of local presence positively affects both product tangibility and product likability. Both factors positively influence purchase intention [Verhagen et al. 2014].

In other words, the more a customer is able to directly and interactively experience a product, the more salient and appealing the product appears to be, which results in a stronger purchase intention. This approach could be pursued in the field of medical room planning, using VR product visualization together with customers on a regular basis.

Figure 21 shows a combined overview of the results the two studies focusing on VR product presentation.

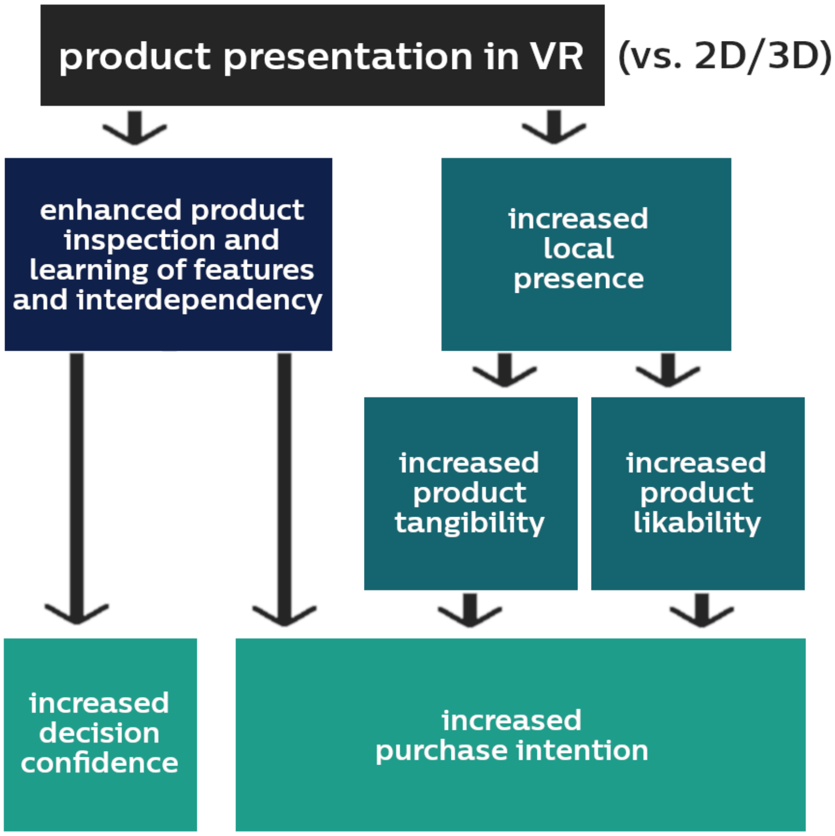

Figure 21: An overview of the effects of product presentation in VR instead in comparison to 2D and 3D visualization. Ultimately, decision confidence and purchase intention are positively affected. Own combined illustration of the findings of two experimental studies [Yoon et al. 2008] and [Verhagen et al. 2014].

5.4. Recommendations for further development

The most prominent model requests and feature ideas (described in chapter 5.2.) led to tangible suggestions how the concerned aspects could be improved during further development:

- A model of a standardized patient bed could be included in the model catalog. This could either be static or animated, to enable customers to test maneuvering through the room setup within VR mode. This applies to movable device parts in general, to enable customers to test all possible states of a room layout directly within VR mode.

- The possibility of placing several objects of the same type could be implemented, as a room sometimes possesses more than one door.

- A saving functionality could be implemented, to enable users to re-open previous room layouts and to prepare room layouts in advance.

A saving functionality could either be local (on the respective smartphone, stored in the local memory) and only serve as recovery for room layouts if the app is closed (or crashes) and is re-opened afterwards. Another possibility would be the storage of multiple states, though still locally. This would enable the user to save different versions or alternatives of one room layout to re-assess them. Additionally, the raw data of room layouts could be exported in the file browser as a special data type to be opened in another instance of the RRPT on another smartphone. The most sophisticated and complex possibility of a saving functionality would be a cloud-based or database storing functionality. As an integrated solution, this would enable users to easily share, export and import room layouts directly within the RRPT.

- A measuring feature could be implemented, represented in 2D mode as distance indicators of an object to its neighbor objects and walls, visible as long as the respective object is selected. Considerations in this evaluation did not conclude if a measuring feature is needed in 3D mode nor what it should behave like. In contrast, many ideas were outlined concerning measuring in VR mode: One possibility would be to assign one button of the handheld controller (e.g. the middle one labelled with “-“) to the interaction of toggling a measuring mode. The user would point the controller tip to an object in VR and while the button is pressed, the distances to neighbor objects and walls would be displayed, either on the floor or mid-air.

- Additionally, ambient lighting could be included in the RRPT, with luminous areas on walls or the ceiling or in between. The general room style could be made configurable like it is possible in the Philips Vive tool (chapter 2.1.) with at least two different styles to be selected.

6. Creation of additional content for the RRPT application

Some conclusions (i.e. possible solutions) to most prominent feedback were straightforward and did not involve additional software development but did involve graphic design, and thus were included in the scope of this work. Some of the primarily discussed points were closely investigated in order to directly derive a concept for additional graphical assets that were subsequently created to effectively support the further development of the RRPT.

6.1. Design of new viewpoint icon

As frequently observed in user tests, the icon for "set viewpoint" was often misinterpreted as a "power button" due to its circular shape intersected by a vertical line (see Fig. 22). The antecedent master's thesis [Maleta 2018] does not describe in detail why the particular icon was chosen or designed that way.

After personal discussion with employees and customers after observed user tests, the consensus arised that the viewpoint icon should be redesigned during further development of the RRPT prototype. The *Philips Asset Library* (https://www.assetlibrary.philips.com/) does not provide any kind of viewpoint or direction icon. Subsequently, a new design approach was chosen, considering the following factors.

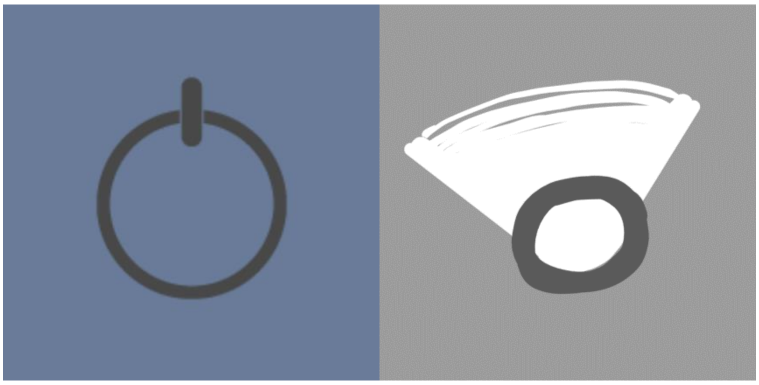

Figure 22: *On the left: Initial viewpoint icon in first RRPT prototype. On the right: Sketch of cone-shaped new icon for further development. Basis for the following final design.*

For the basic form, a cone-shaped form was found to be most appropriate and most commonly represented in the minds of potential user groups. As the main reference of comparable icons for this viewpoint or direction mechanics Google Maps was named by many respondents. After a sketch (see Fig. 22) and feedback cycles, the final design approach (see Fig. 23) was created with the Google Maps design in mind, but simpler and in grayscale. Similarly, a gradient from the center outwards (fading to transparent) is used to indicate the field of view. White or dark gray serve as accent tones to ensure maximal visibility on various background colors. For instance, the VR environment is held in white or very light gray tones, so the version with the medium gray accent (Fig. 23, upper right corner) would be the favorable option for this asset to be implemented.

Another differentiator to Google Maps is the view cone angle, it does not alter but is fixed to 100°, which represents a normal field of view in VR.

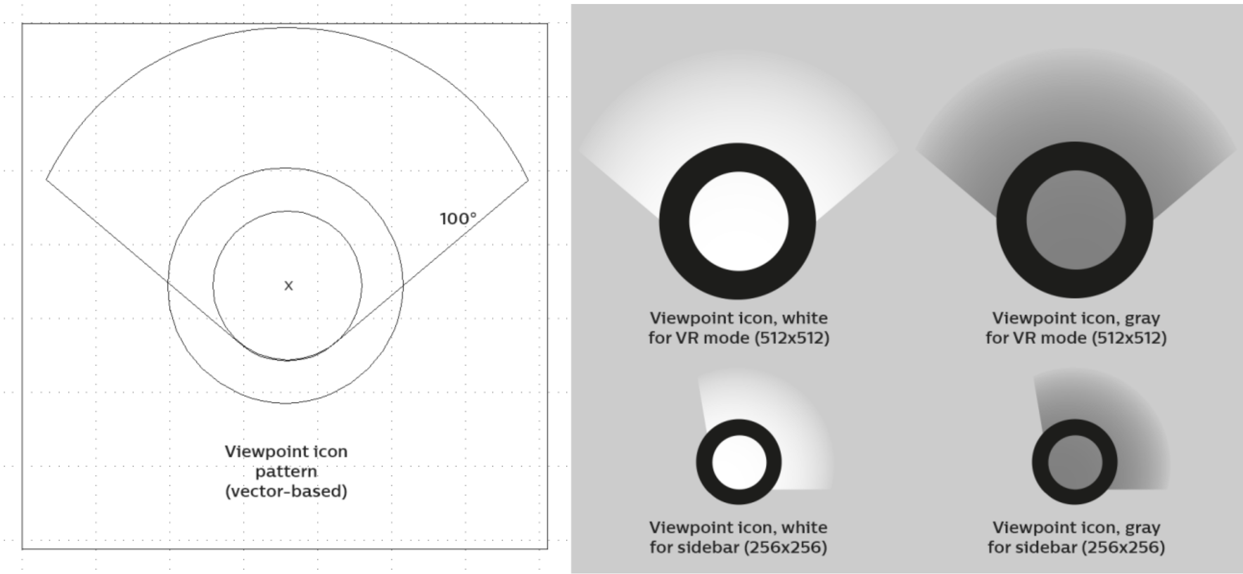

Figure 23: On the left: basic icon pattern of newly designed viewpoint icon with centered ring shape and cone shape in view direction. On the right: resulting final versions for different uses. The HEX values are: dark gray (1d1d1b) for the ring, white (ffffff) and medium gray (808080) for the cones.

It is important that the circular shape is perfectly centered in the square matrix to make sure that while rotating, the perceived position of the viewpoint – which equals the virtual standing position of the user in 3D and VR mode – does not change.

The viewpoint icon will be used in the side bar in 2D mode to indicate the “set viewpoint” functionality, replacing the old “power button”-like viewpoint icon. All GUI icons in the RRPT have a matrix size of 256x256. Additionally, an entirely new use of the icon is intended in VR mode: indicating the floor position of the viewpoints previously set. For this purpose, matrix size of 512x512 is more appropriate.

All files were created using Adobe Creative Cloud (Illustrator, Photoshop).

6.2. Design of in-app help and interaction overview screens

As stated in chapter 4.4. and 5.4., many usability findings were identified across all user tests. The most prominent aspects lead to the idea of creating a tutorial-like overview of the basic and central interaction mechanics, such as settings and gestures. The reason for the creation and planned implementation of such help screens is the expectation that they will mitigate the probability and severity of the most prominent usability problems: editing of room dimensions, selection of room shape, object catalogue (side bar) and viewpoint mechanics and the general gestures to manipulate objects – these points constitute the content of the interaction overview screens. For the number of serial screens to be examined by the user, three was found to be appropriate, because the content included in this tutorial can be attributed to three main categories: room settings, object manipulation and gestures.

The visual style was chosen to be abstract instead of labelled screenshots of the actual app screens (in prototype state). One advantage of this choice is that even if the visual style of the app or details in the GUI change, the overview screens remain valid. Radical changes, such as completely different gestures, would result in the invalidity of the overview screens. Another advantage is the possibility to easily translate the help screens by editing text fields.

The overview screens are designed to be Philips brand conform, as the app was developed together with and for Philips and is currently solely used by Philips Healthcare employees. The blue color tones match the official Philips color palette ("group blue 1, 2, and 3"). Most of the graphical assets (icons) used in the screens originate from design files (.ai) in the *Philips Asset Library* (https://www.assetlibrary.philips.com/) and are only used in their designated meaning or context. The hand gesture pictograms (named *Gesty*) used in the third screen (Fig. 24, on the right) were created and distributed with free licensing by web developer Mariusz Ostrowski (https://github.com/mariuszostrowski/gesty). The only newly created icon for the RRPT is the viewpoint icon (as described in chapter 6.1.). The side bar version (256 px) is used in this context.

Figure 24 shows a combination of the three designed interaction overview screens.

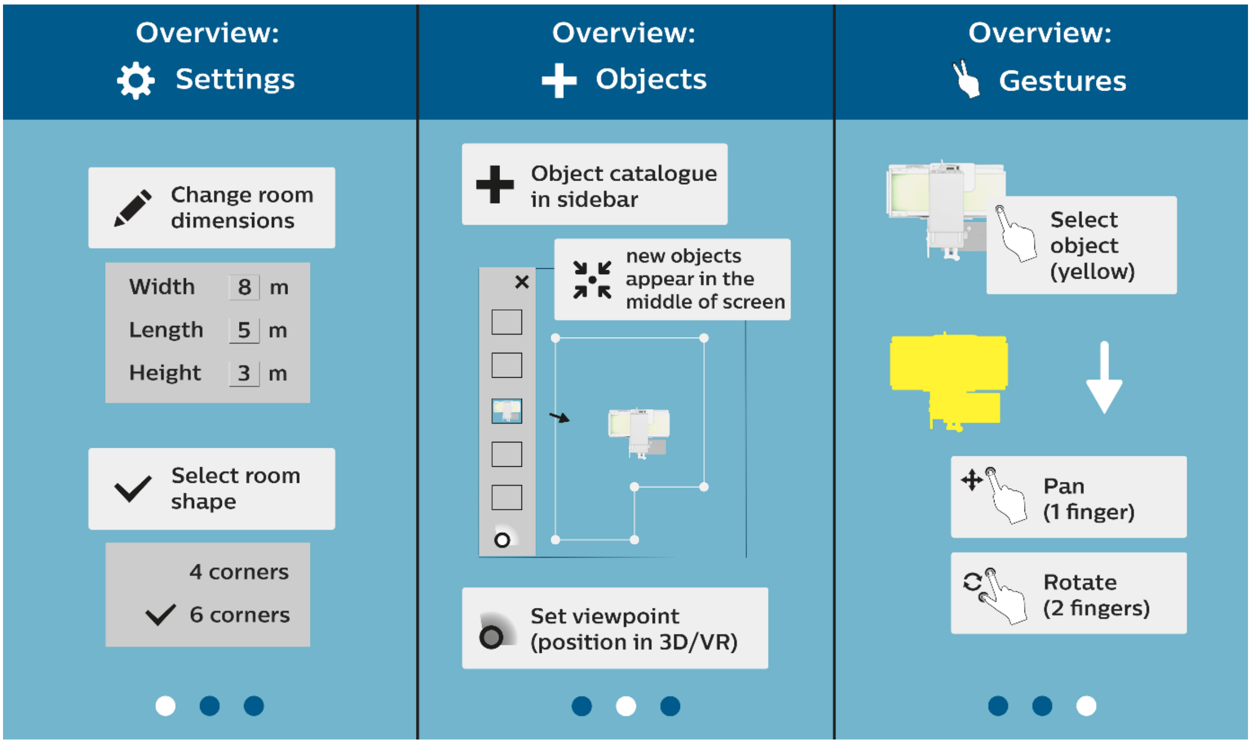

Figure 24: Three interaction tutorial pages concerning the three important areas within the app: room settings, object arrangement and manipulation gestures. Implemented in serial order, according to the order indicator (dots at the bottom of each screen).

Two different smartphone models are currently used as hardware platforms for the RRPT: Google Pixel or Samsung Galaxy S8. The screen resolutions differ: 2560x1440 px for the Google Pixel models and 2960x1440 px for the Samsung Galaxy S8. Considering this, two different screen ratios of the interaction overview (2560x1440 and 2720x1440) exist to facilitate the implementation on both smartphone models.

It is planned that the screens will be displayed on first encounter of the app to introduce new users, but also be available in a help section in the footer menu in order to be able to be revisited again to support the learning effect.

All screens in all ratios were created both in German and in English. Although the current language of the RRPT is German, it is possible that – once the tool gets more accepted and internally spread – the language will be changed to English; In that case the overview screens would not have to be re-designed in the same manner again. English is universal for software GUIs, so another language is not likely to be needed. All files were created using Adobe Creative Cloud (Illustrator, Photoshop).

6.3. Texturizing of 3D models

Initially, the models of Philips devices that are implemented in the RRPT were converted from CAD models and reduced in the number of polygons within the antecedent master's thesis [Maleta 2018]. Some smaller adjustments of texture remained, so they were included in this bachelor's thesis. One model, the *CombiDiagnost R90*, did not possess the correct model surface properties to look realistic (see Fig. 25), colors needed to be adjusted. The original look according to official marketing material product renderings [Philips Healthcare 2017] was taken as reference.

Figure 25: Product renderings of Philips Fluoroscopy Devices. From left to right: Vertical Stand, ceiling-mounted CSM, CombiDiagnost R90 [Philips Healthcare 2017].

The editing of surfaces and textures is possible with the 3D modelling software *Autodesk Maya* (version 18.0.0) which is free for students. It contains a special texturing module named *Hypershader*. Figure 26 shows a generic workflow to create a new color on specific surface elements / polygons. First, a new type of material must be created, which can be assigned to selected surface parts in the following step. There are different reflection types; For all RRPT models the surface type *Lambert* was used in order to create a consistent visual impression. Lambert means that the light reflection is distributed equally across the whole solid angle (cone in which the emitted light radiates), so that the surface does not look darker from a respectively shallow angle. As a result, the surfaces look equally bright from any angle and have a dull and smooth impression, as they have on the real devices, too.

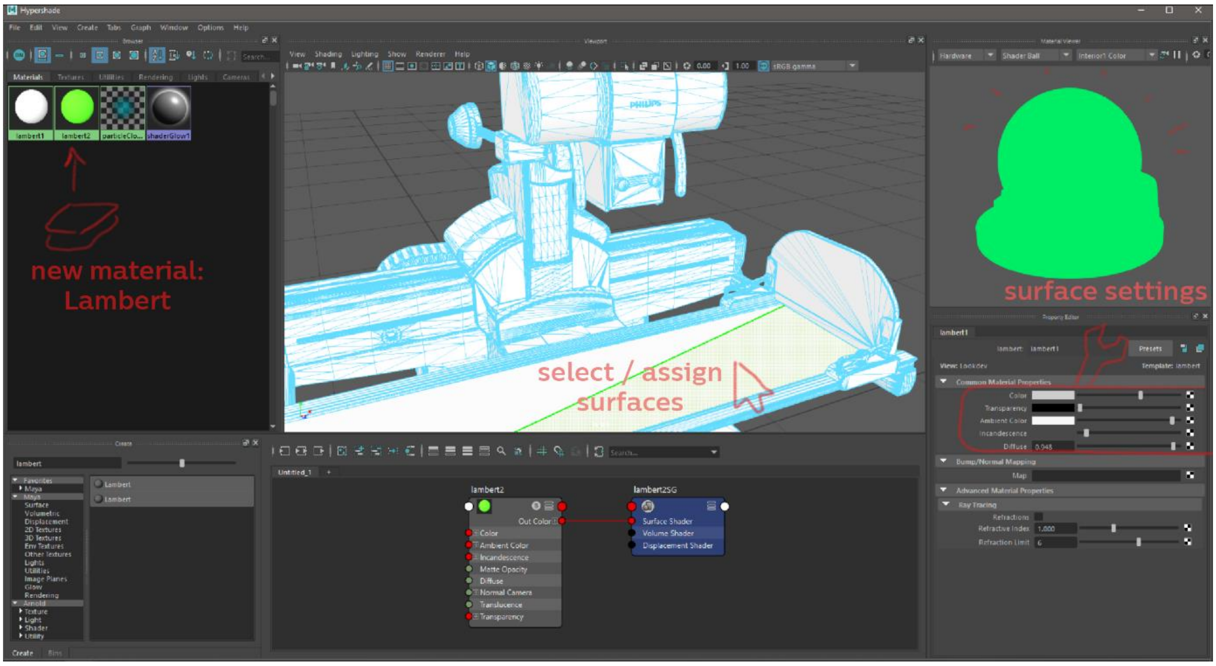

Figure 26: Workflow in Autodesk Maya. On the left: Creation of new material (lambert emitter). In the Middle: Assignment of affected surfaces. On the right: Setting of surface parameters.

The newly colored model of CombiDiagnost R90 is implemented in the RRPT among other existing models. When combined in one common virtual environment, the perception arises that in VR mode, some of the surfaces seem to appear darker than others even though they look the same in 3D mode. This appearance discrepancy originates in a different lighting technique in 3D and VR mode: 3D mode uses external light sources that are reflected on the lambert surfaces whereas VR mode does not use an external lighting source. Subsequently, surfaces must possess the property of self-luminosity for proper appearance in VR mode. This information was not included in the texturing process of this work but may be implemented in future revisions of the model set.

7. Summary: key insights and roadmap opportunities for further development

The benchmark chapter reveals a multitude of successful VR applications in comparable fields of high involvement marketing and sales, relevant and interesting features are outlined for consideration in further development.

Customer-focused VR applications are thought to save many planning iterations in comparable high involvement room planning cases, accelerate customer feedback cycles and increase effectivity and efficiency. These findings could be extended to medical room planning as well. In effect, a mobile VR rapid room planning tool could deliver a more viable and experiental basis for further room layout drawings and possibly save pre-sale iterations in an early stage in room planning projects, which would result in decreased project costs. Corresponding considerations and recommendations for the planning iteration assessment are outlined.

This work includes a usability assessment of a current prototype state of the RRPT. Observed user tests with Philips Healthcare employees reveal a high level of usability with medians at 3 (maximum) in 7 of 9 tasks. Additionally, specific findings were collected and led to tangible recommendations for the further development of the application.

This evaluation shows that the idea of a 2D/3D/VR workflow for room planning tool is widely accepted, both internally (Philips Healthcare employees) and externally (customers, i.e. healthcare professionals). Respective survey results show high medians: In the customer acceptance evaluation, 9 of 11 are at 5 (++) of possible 6 (+++) or above. In the employee evaluation, 13 of 15 are at 5 (++) or above. Furthermore, employee survey results prove to be statistically independent of customer proximity and age.

The evaluated planning tool enables mobile rapid room planning on smartphones and can be used quickly (no extensive hardware and software setup) and while remaining seated or standing. Customer feedback shows that these aspects motivate even hesitating customers to try it within a conversational setting. Rapid planning of medical imaging rooms is reported to be a functional use case, as most users don't criticize the simplicity of models. Every mode of the application (2D, 3D, VR) is reported to have its benefit in specific situations.

Customers report that the VR visualization improves their spatial imagination of device proportions in the anticipated environment in comparison to traditional product presentation media (2D pictures and videos). This finding is consistent with literature, as four studies report that visual imagery and especially VR visualization helps imagining real proportions of objects and produces a sense of local presence for the (non-present) products, which helps customers learn product features and understand interdependency. These factors ultimately result in enhanced decision confidence and increased purchase intention.

This work concludes with a categorized overview of recommendations for further development of the RRPT application. The overall findings (usability issues, model requests and feature ideas) were prioritized, integrated and subsequently divided into 3 conceivable concepts for further development: basic enabler functionalities, important key functionalities and a high-end solution (see Fig. 27).

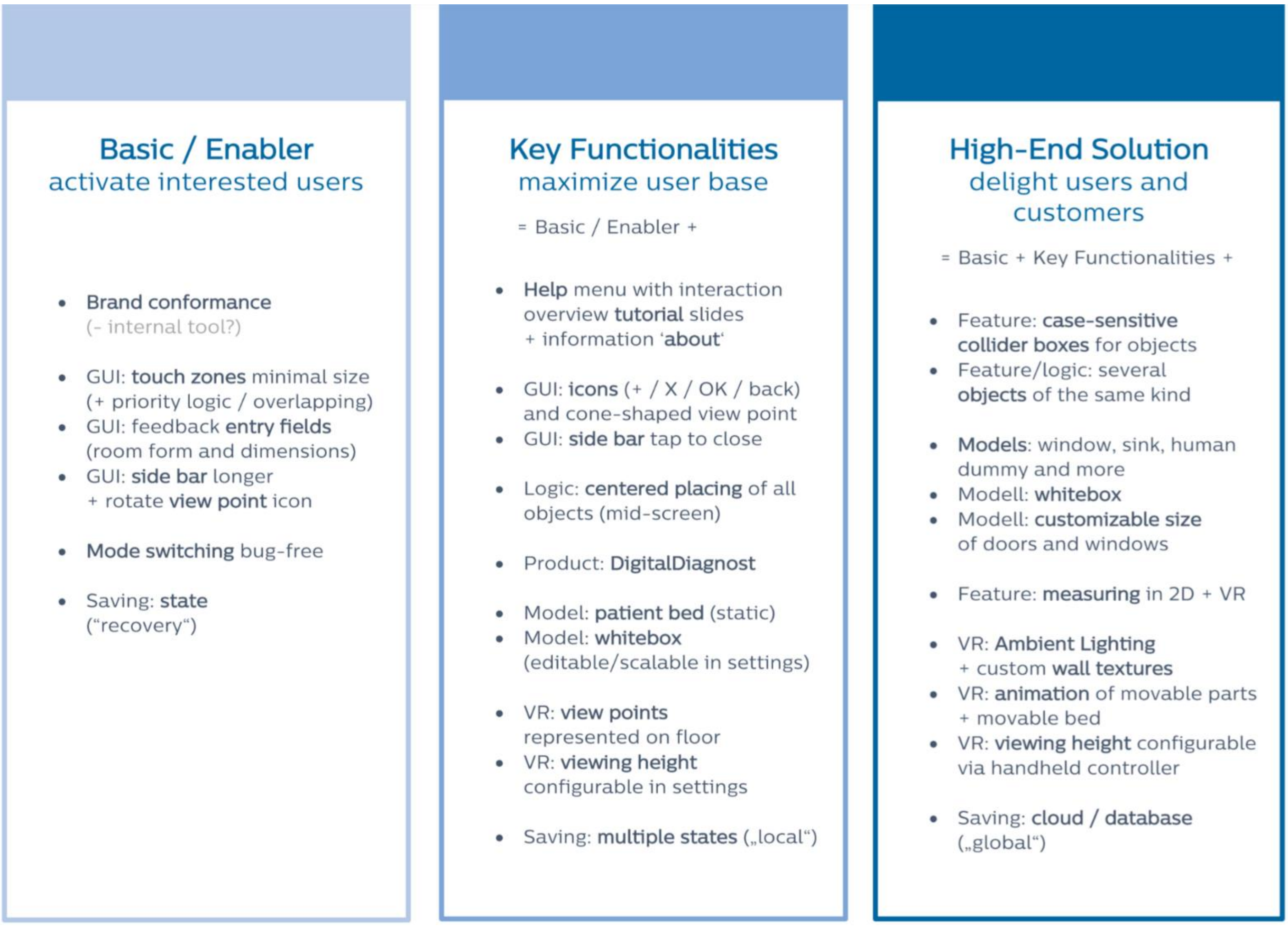

Figure 27: Three conceivable concepts for the further development of the RRPT, the second and third build on the previous one, so that consequently, the last concept embraces all points that are denoted. "Basic/Enabler" provides the most important changes for the tool to be internally usable. "Key Functionalities" extends the application with the most prominent features that were discussed with both employees and customers. The high-end solution covers all points that have been identified as viable concepts for a future state of the RRPT to delight both employees and healthcare professionals.

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9. Appendix

9.1. Complete list of all usability findings, model requests and feature ideas based on employee and customer feedback

Category	ID	Description	Relative frequency 1-3 (3=high)
GUI / interaction - Usability issues	G1	Touchzones expected to be fullscreen	3
	G2	Viewpoint-Icon mistaken as power button -> cone-shaped as in Google Maps would be better	3
	G3	Settings: missing feedback for selection of room shape	3
	G4	Settings: users expected "OK" instead "X" button	3
	G5	Settings: numerical entry fields don't look editable	3
	G6	VR Controller: "-" is not expected to be VR-close	3
	G7	Sidebar: users tapped next to sidebar for close	3
	G8	Sidebar: Elements are expected to be drag&drop	2
	G9	Users expected all objects to appear mid-screen	2
	G10	Catalog-"+" too transparent, not visible	2
	G11	Close-"X" on GUI toplevel was not expected	2
	G12	VR: default view height was stated to be too low	2
	G13	Sidebar: viewpoint label is not visible, overlapped	2
	G14	Sidebar: back-arrow is too clunky/big	1
	G15	Info button was not expected on GUI toplevel	1
Models requests - summary	M1	Standard patient bed	3
	M2	Variable door width	3
	M3	Human dummy (standing)	2
	M4	variable dummy boxen “whiteboxes”	2

	M5	Sink	1
	M6	Window	1
Feature ideas - summary	F1	Saving functionality, either local or cloud-based	3
	F2	Export of raw data of room layouts	2
	F3	Several objects of the same kind at a time	3
	F4	Animation of movable parts	2
	F5	Ambient Lighting on walls	2
	F6	VR: configurable view height	2
	F7	VR: viewpoints visually marked on floor	2
	F8	VR: handheld controller: "-" assigned to measurements on/off	2
	F9	Case-sensitive collider-boxes depending on the use case of devices	1
	F10	Wall texture customizable	1

9.2. Details of usability / UX evaluation (Philips employees)

9.2.1. Evaluation documents

The evaluation in this work was conducted using the following (original) documents, which are written in German. This applies for the following chapter (usability/UX evaluation) as well as for the later chapter of customer acceptance evaluation documents (chapter 9.3.1.).

All test participants' primary language had been expected to be German and has been in fact. For this reason, all tests with Philips Healthcare employees at three different locations in Germany and with healthcare professionals at the radiology congress were conducted in German. The questions and results were translated afterwards, including feedback cycles, to represent the original meaning as well as possible.

The subsequent histograms (distribution) of the results are in English.

Beobachtungsbogen - VR- Rapid Room Planning Tool

-> Kürzel Beobachter: _________ + Nummer Nutzer: _____

Task 1: (2D) Raum konfigurieren (ZEIT STARTEN !)

„Konfigurieren Sie bitte zu allererst einen 6-eckigen Raum mit beliebiger Länge und Breite, die Höhe können Sie beibehalten."

O	**Raumform /–maße** anpassen	*Einstellungen -> 4/6 Ecken -> num. Eingabe -> „X"*
Score	Notizen: O numerische Eingabe der Maße O durch Ziehen der Eckpunkte	

Task 2: (2D) Objekte hinzufügen und anpassen

„Erstellen Sie ein realistisches Setup mit 2 Geräten, einem Generatorschrank plus Tür oder Fenster. Verschieben Sie gegebenenfalls die Objekte, damit die Positionierung und Ausrichtung passt."

O	**4 Modelle** hinzufügen: 2 Geräte, Schrank, Tür	*Katalog „+" -> Modell -> Bildschirmmitte*
Score	Notizen:	

„Danach fügen Sie bitte noch mindestens 3 Viewpoints hinzu, um sich den Raum gleich von verschiedenen Blickwinkeln aus anschauen zu können."

O	mind. **3 Viewpoints** hinzufügen	*Katalog „+" -> Viewpoint (unten) -> Bildschirmmitte*
Score	Notizen:	

O	**(allg) Gesten:** Anwählen, Verschieben, Drehen	*1-F-Tap, 1-F-Drag, 2-F-Rotate*
Score	Notizen:	

(2D FERTIG, ZEIT BIS JETZT EINTRAGEN !) -> Zeit 2D: ______________

Task 3: (3D) Check in 3D-View

"So, fertig – nun können Sie sich das Ganze mal im 3D-Modus ansehen!"

O	3D-Modus finden	*Obere Leiste -> „3D"*
Score	Notizen:	

"Schauen Sie sich genau um, passt das so? Sind die Objekte richtig platziert?"

O	- Orbit 3D-View - Zoom 3D-View	- *1-F-Drag* - *2-F-Pinch*
Score	Notizen:	

"Sie hatten ja vorher Viewpoints gesetzt – begeben Sie sich mal in alle diese Blickwinkel hinein."

O	Viewpoints durchschalten	*„Augen-symbol" unten -> Links-Rechts-Pfeile*
Score	Notizen:	

Task 4: (VR) Check in VR-View

"Zu guter Letzt können Sie sich per Virtual Reality einen Eindruck ihres soeben gestalteten Raums verschaffen! Dafür haben wir eben diese Google Daydream -Brille inkl. Controller hier."

O	VR-Modus finden	*Obere Leiste -> „VR"*
Score	Notizen:	

O	Smartphone in HMD einlegen, Fernbedienung aktivieren	*Daydream-Anweisungen folgen*
Score	Notizen:	

O	Viewpoints durchschalten und umhersehen	*Links/Rechts auf Daydream-Fernbedienung, Kopfbewegung*
Score	Notizen:	

Bewertungsbogen für VR- Rapid Room Planning Tool

(Kürzel Beobachter: _____ + Nummer: ___) -> Auswertung erfolgt anonym!

Abteilung: ____________________ / **Produktbereich**: ____________________

seit _____ Jahren **Alter**: ○ 20-30 | ○ 30-40 | ○ 40-50 | ○ 50-65

Spezielle Anmerkungen / Feedback / konkrete Verbesserungsvorschläge – falls vorhanden – bitte in die jeweiligen Boxen unter jeden Aspekt. Vielen Dank für Ihre Mithilfe!

Aufgabenangemessenheit (~ Unterstützung bei Erledigung der Aufgaben)

Die App...	---	--	-	+	++	+++	Die App...
würde ich im Alltag als Unterstützung in Kundengesprächen **nicht verwenden**.							würde ich im Alltag als Unterstützung in Kundengesprächen **verwenden**.
ist allgemein **kompliziert zu bedienen**.							ist allgemein **einfach zu bedienen**.
bietet **nicht alle Funktionen**, um die Planung **effizient** durchzuführen.							bietet **alle Funktionen**, um die Planung **effizient** durchzuführen.
Kommentare							

Erwartungskonformität (~ Anlehnung an gewohnte Konzepte)

Die App...	---	--	-	+	++	+++	Die App...
weist **zu viele verschiedene** und zum Teil **ungeläufige Gesten** auf.							lässt sich mit **wenigen** aber **bekannten Gesten** bedienen.
Kommentare							

Steuerbarkeit (~ Beeinflussungsmöglichkeit je nach Arbeitsweise)

Die App...	---	--	-	+	++	+++	Die App...
erschwert den **Wechsel** zwischen verschiedenen Menüs und Modi.							ermöglicht **leichten Wechsel** zwischen verschiedenen Menüs und Modi.
weist eine **zu niedrige Sensitivität der Gesten** [Touchzones (Angriffsflächen) für das Verschieben von Objekten] auf							weist eine **sehr gute Sensitivität der Gesten** [Touchzones (Angriffsflächen) für das Verschieben von Objekten] auf
Kommentare							

Selbstbeschreibung (~ genügende und verständliche Erklärungen)

Die App...	---	--	-	+	++	+++	Die App...
bietet einen **schlechten Überblick** über die gesamte Funktionalität.							bietet einen **guten Überblick** über die gesamte Funktionalität.
enthält **kryptische** Begriffe, Abkürzungen, Labels und Icons.							enthält **verständliche** Begriffe, Abkürzungen, Labels und Icons.
Kommentare							

Fehlertoleranz (~ Hinweise und Korrekturmöglichkeiten bei Eingaben)

Die App...	---	--	-	+	++	+++	Die App...
informiert **schlecht verständlich** über unzulässige Eingaben oder Anordnungen (Kollisionen).							informiert **gut verständlich** über unzulässige Eingaben oder Anordnungen (Kollisionen).
Kommentare							

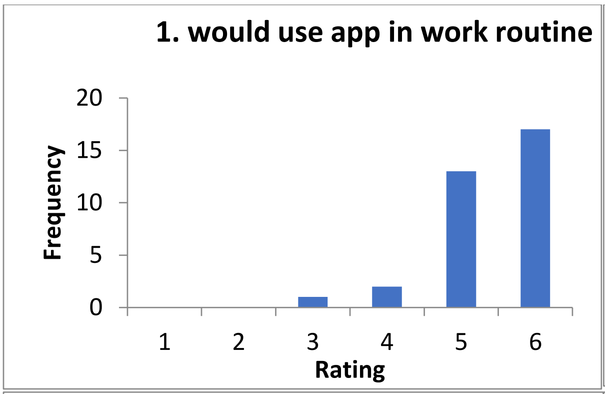
Lernförderlichkeit (~ leichte Einarbeitung und angemessene Lernkurve)

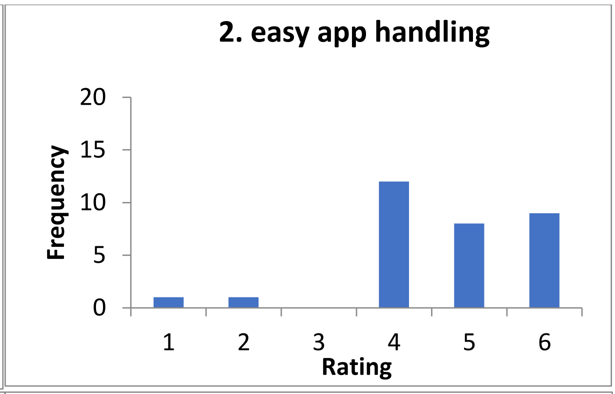
Die App...	---	--	-	+	++	+++	Die App...
erfordert **viel Hilfe** zur **Einarbeitung**.							erfordert **keine Hilfe** zur **Einarbeitung**.
Kommentare							

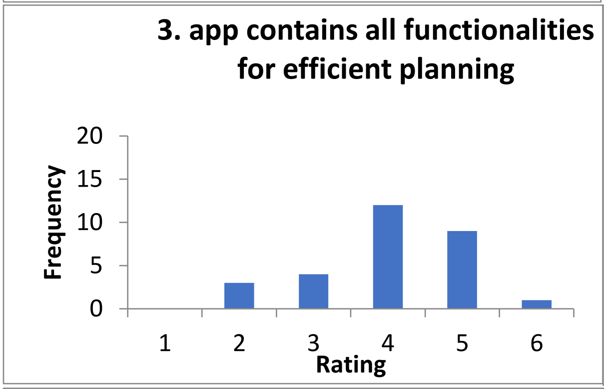
speziell: **Virtual Reality**

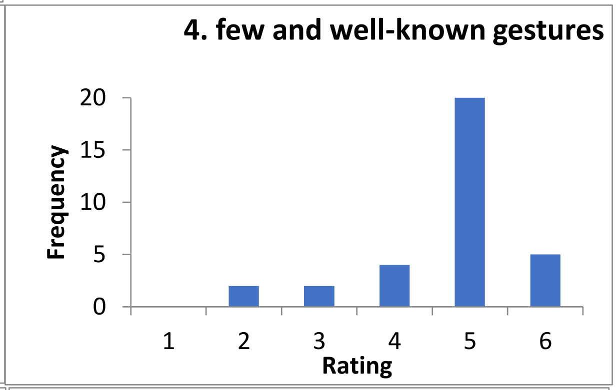
	---	--	-	+	++	+++	
Ich habe **keinerlei VR-Vorerfahrung**.							Ich habe bereits **viel VR-Vorerfahrung**.
Ich empfand das VR-Erlebnis als **unangenehm** (körperlich, visuell).							Ich empfand das VR-Erlebnis als **angenehm** (körperlich, visuell).
Ich hätte **Hemmungen**, ein VR-Headset in einem echten Kundengespräch zu verwenden.							Ich hätte **keine Hemmungen**, ein VR-Headset in einem echten Kundengespräch zu verwenden.
Der VR-Modus **trägt nicht** zur Verbesserung der räumlichen Vorstellung des geplanten Raums **bei**.							Der VR-Modus **trägt** zur Verbesserung der räumlichen Vorstellung des geplanten Raums **bei**.
Die Steuerung mithilfe des **Controllers** (Fernbedienung) ist **verwirrend**.							Die Steuerung mithilfe des **Controllers** (Fernbedienung) ist **intuitiv**.
Die **Modelle** im VR-Modus sehen **unrealistisch** aus.							Die **Modelle** im VR-Modus sehen **realistisch genug** (für ein RRPT) aus.
Kommentare							

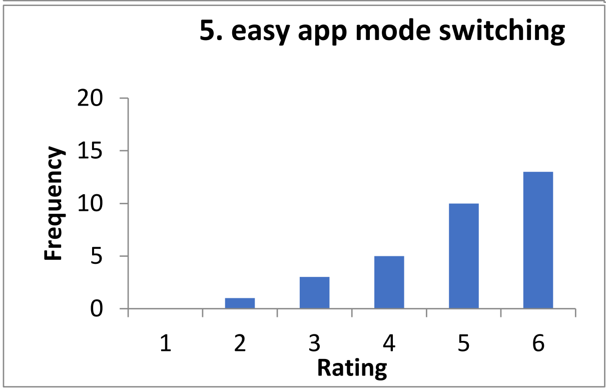
9.2.2. Histograms of questionnaire

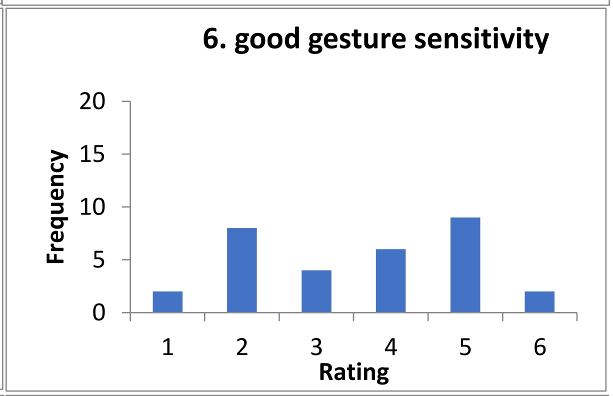


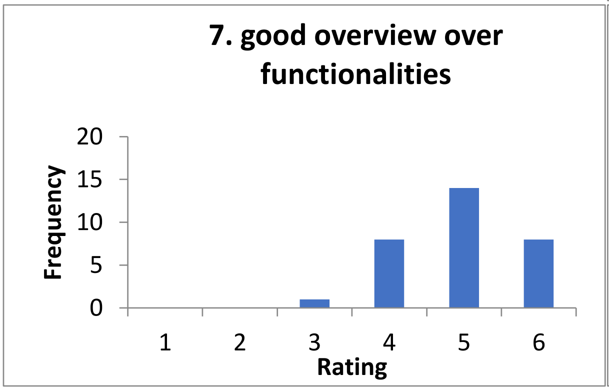


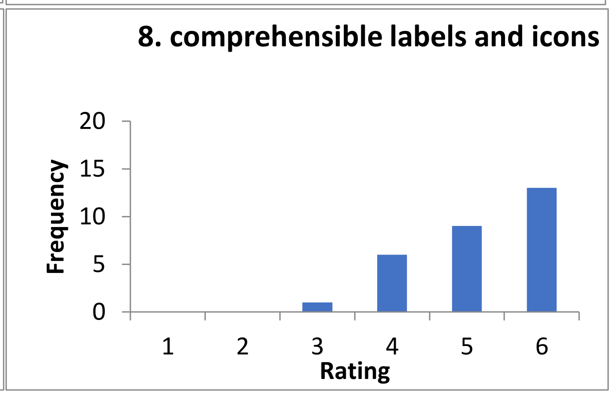


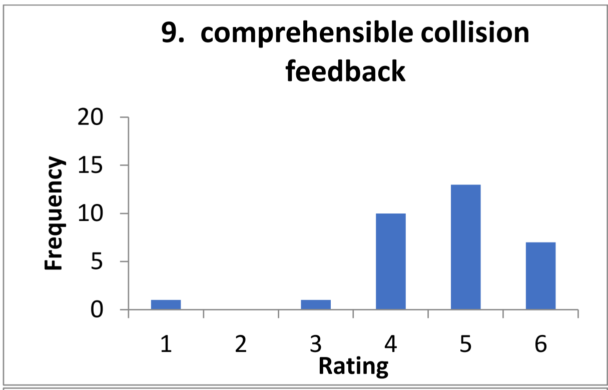


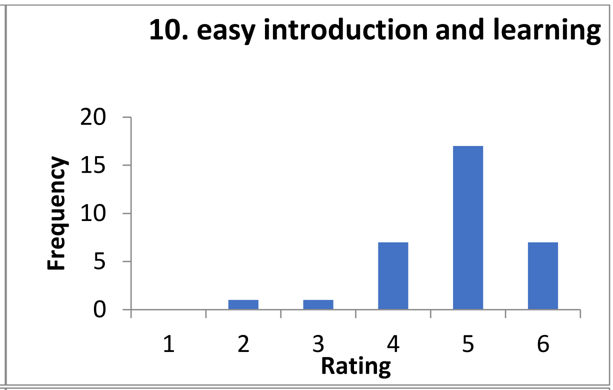


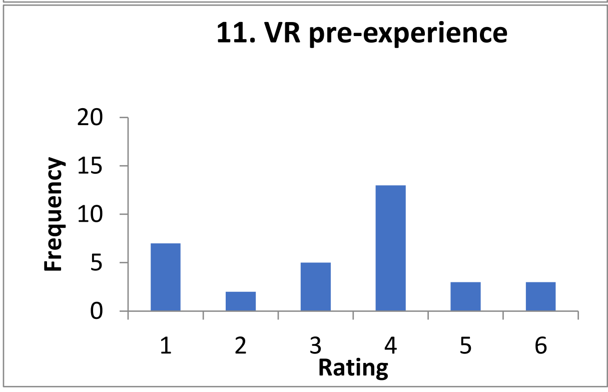


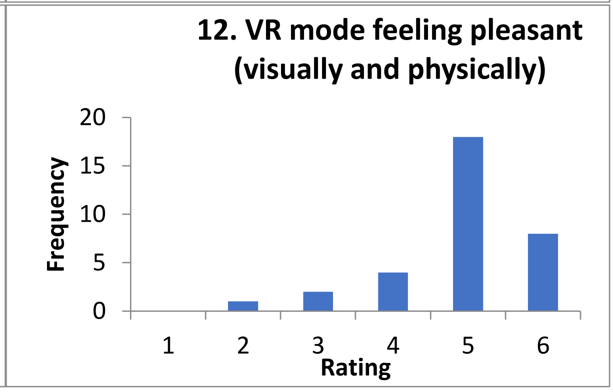


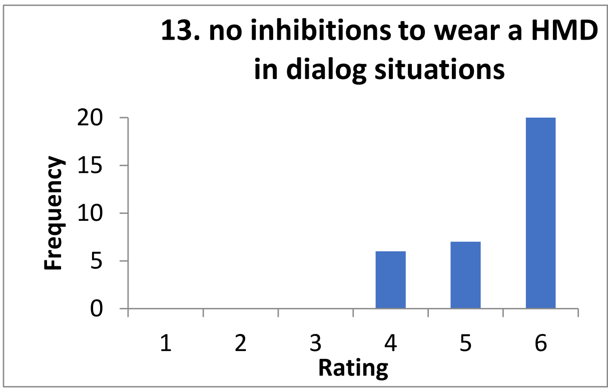


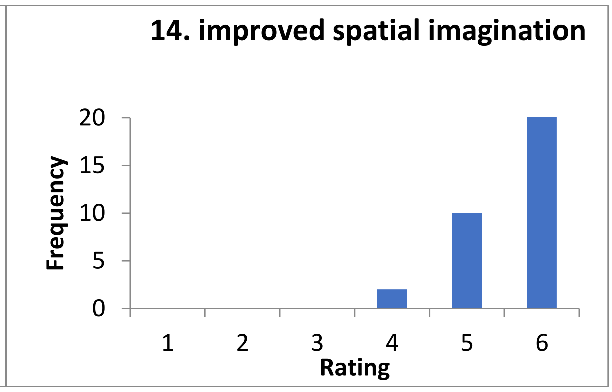

9. comprehensible collision feedback
Frequency
Rating

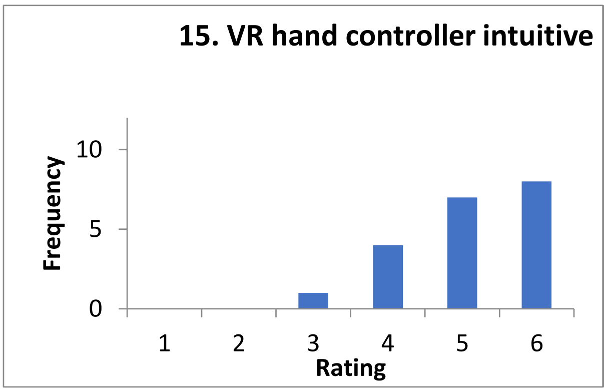

10. easy introduction and learning
Frequency
Rating

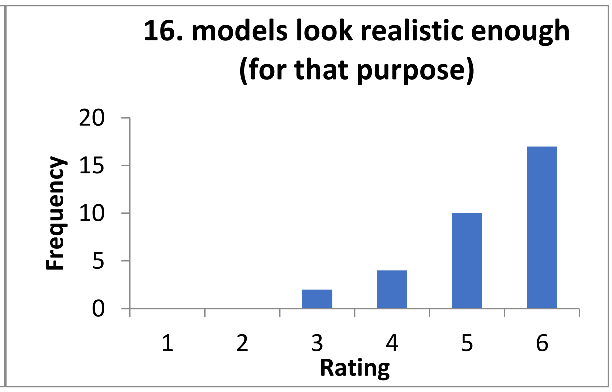

11. VR pre-experience
Frequency
Rating


12. VR mode feeling pleasant (visually and physically)
Frequency
Rating


13. no inhibitions to wear a HMD in dialog situations
Frequency
Rating


14. improved spatial imagination
Frequency
Rating


15. VR hand controller intuitive
Frequency
Rating


16. models look realistic enough (for that purpose)
Frequency
Rating

9.2.3. T-test results with user groups split in customer proximity

Question number	Mean value (near)	Mean value (far)	Variance (near)	Variance (far)	Actual t-value	Critical t-value
1	5.357	5.357	0.709	0.555	0	**2.055**
2	4.929	4.417	1.918	1.174	1.056	**2.064**
3	3.846	4	0.974	1	-0.378	**2.079**
4	4.785	4.785	0.950	0.797	0	**2.055**
5	4.857	4.846	1.208	1.641	0.023	**2.063**
6	3.857	3.167	2.439	2.333	1.137	**2.063**
7	5.153	4.692	0.474	0.730	1.515	**2.068**
8	5.181	5.230	1.163	0.692	-0.122	**2.093**
9	4.642	4.923	1.631	0.576	-0.698	**2.079**
10	4.928	4.857	0.532	0.593	0.251	**2.055**
11	3.142	3.714	2.131	3.296	-0.917	**2.059**
12	4.928	4.928	1.148	0.994	0	**2.055**
13	5.642	5.285	0.401	0.835	1.201	**2.068**
14	5.714	5.428	0.373	0.417	1.201	**2.055**
15	5.083	5.166	0.628	1.366	-0.157	**2.364**
16	5.285	5.142	0.989	0.901	0.388	**2.055**

9.2.4. T-test results with user groups split in age

Question number	Mean value (young)	Mean value (old)	Variance (young)	Variance (old)	Actual t-value	Critical t-value
1	5.2	5.6	0.743	0.257	-1.549	**2.068**
2	4.929	4.642	0.840	1.785	0.659	**2.068**
3	3.769	4.231	1.359	0.692	-1.161	**2.073**
4	4.667	4.867	0.952	0.981	-0.557	**2.048**
5	4.933	4.786	1.924	0.643	0.353	**2.068**
6	3.4	3.846	2.114	2.141	-0.807	**2.059**
7	4.857	5.071	0.593	0.533	-0.755	**2.055**
8	5.154	5.307	1.141	0.564	-0.424	**2.073**
9	4.667	4.928	1.524	0.841	-0.651	**2.055**
10	4.8	4.8	0.743	1.028	0	**2.051**

11	3.467	3.2	2.838	2.029	0.468	**2.051**
12	5	4.867	1.714	0.267	0.367	**2.101**
13	5.333	5.533	0.952	0.267	-0.702	**2.079**
14	5.533	5.6	0.409	0.4	-0.287	**2.048**
15	5.3	4.778	0.455	1.194	1.236	**2.160**
16	5.133	5.4	1.124	0.685	-0.768	**2.055**

9.3. Details of customer acceptance evaluation (healthcare professionals)

9.3.1. Evaluation documents

Bewertungsbogen für VR - Rapid Room Planning Tool

(Auswertung erfolgt anonym!)

Beruf: ________________________ / **Produktbereich:** ________________________

seit _____ Jahren **Alter:** ○ 20-30 | ○ 30-40 | ○ 40-50 | ○ 50-65

Spezielle Anmerkungen / Feedback / konkrete Verbesserungsvorschläge – falls vorhanden – bitte in die jeweiligen Boxen unter jeden Aspekt. Vielen herzlichen Dank für Ihre Mithilfe!

Vergleich zu anderen Medien hinsichtlich der räumlichen Vorstellungskraft

im Bezug auf herkömmlich vorhandene Medien der Produktpräsentation

Mein räumliches **Vorstellungsvermögen** für die **Proportionen** der Geräte im Raum hat sich im Vergleich zu… ↓	sehr verschlechtert (- -)	leicht verschlechtert (-)	nicht geändert (0)	leicht verbessert (+)	sehr verbessert (+ +)
… Produkt-**Fotos**					
… Produkt-**Videos**					
… einer realen Produkt-**Präsentation**					
Kommentare					

Aufgabenangemessenheit der Applikation

	- -	-	-	+	++	+++	
Die App würde ich als **Unterstützung** in Beratungsgesprächen **ablehnen**.							Die App würde ich als **Unterstützung** in Beratungsgesprächen **gutheißen**.
Es **fehlen** grundlegende **Funktionalitäten** für eine erste Raumplanung.							Alle nötigen **Funktionalitäten** für eine erste Raumplanung sind **vorhanden**.
Die **Einrichtung** (2D-Modus) dauert **zu lange** bzw. ist ineffizient.							Die **Einrichtung** (2D-Modus) geht **schnell** bzw. effizient vonstatten.
Es **fehlen** grundlegende **Modelle** für ein realistisches Setup eines Raums.							Der Objekt-Katalog enthält alle nötigen **Modelle** für ein realistisches Setup.
Kommentare							

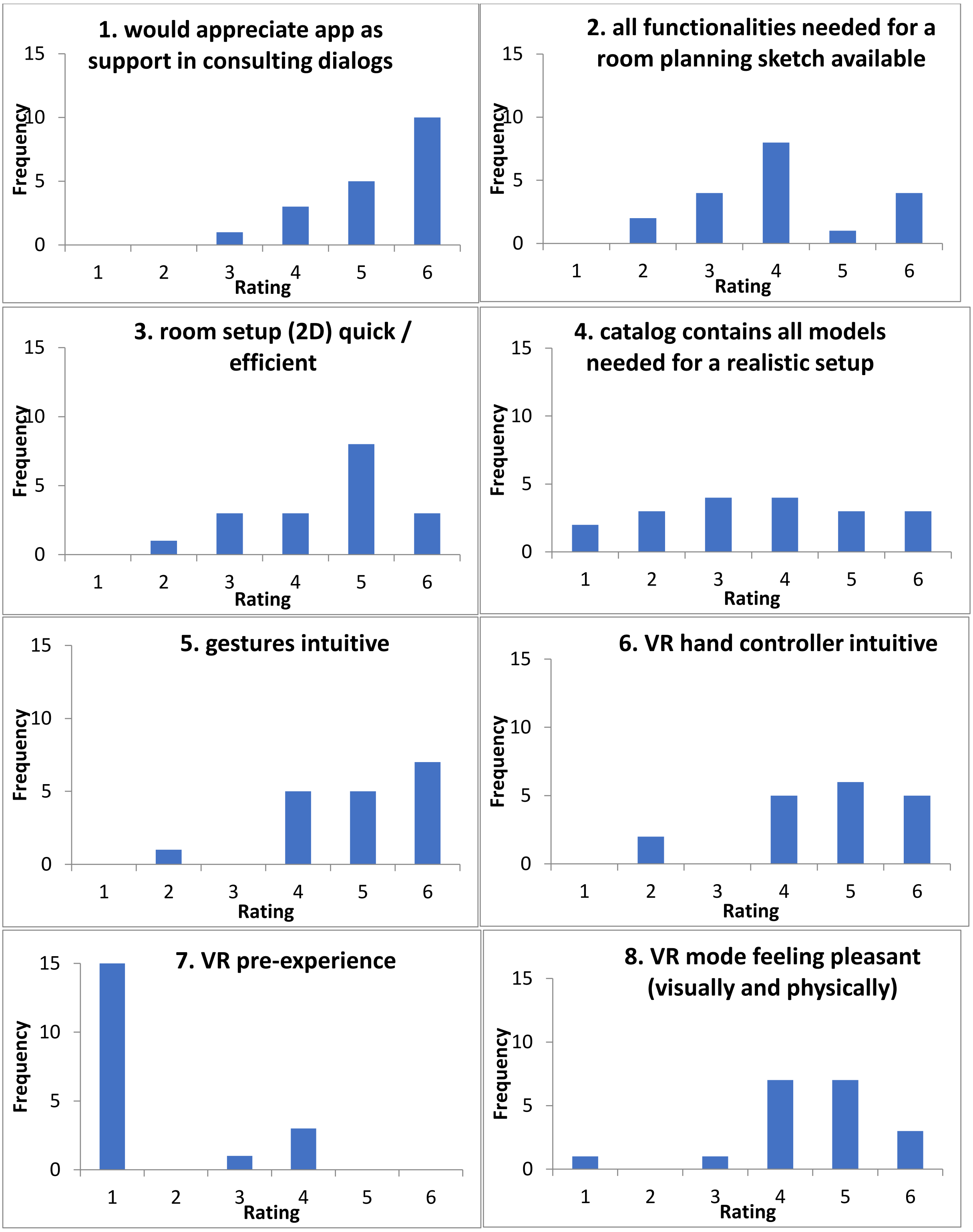
Steuerbarkeit und Erwartungskonformität

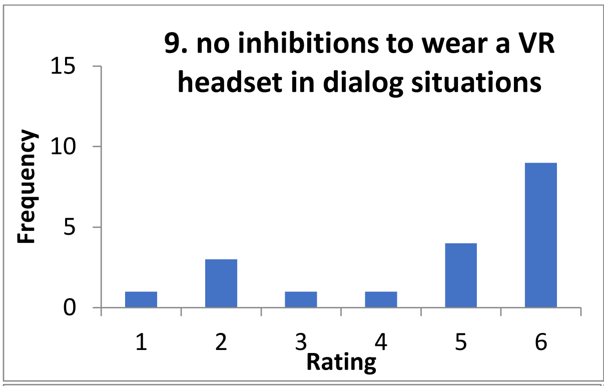
	- - -	- -	-	+	++	+++	
Die **Gesten** im **3D**-Modus sind **verwirrend** / entgegen der Erwartung.							Die **Gesten** im **3D**-Modus sind **intuitiv** / wie von anderen Apps gewohnt.
Die Steuerung im **VR**-Modus mithilfe des Hand-**Controllers** ist **verwirrend** / entgegen der Erwartung.							Die Steuerung im **VR**-Modus mithilfe des Hand-**Controllers** ist **intuitiv** / wie von anderen Apps gewohnt.
Kommentare							

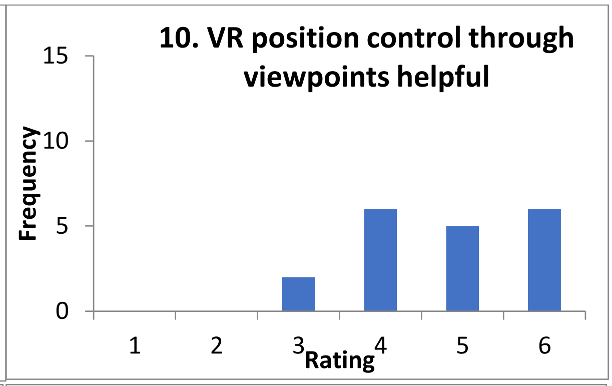
speziell: Virtual Reality

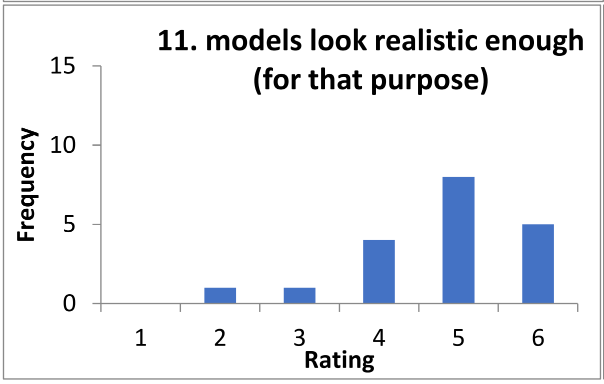
	- -	-	-	+	++	+++	
Ich habe **keinerlei Vorerfahrung** mit VR-Applikationen.							Ich habe bereits **viel Vorerfahrung** mit VR-Applikationen.
Ich empfand das VR-Erlebnis als **unangenehm** (körperlich, visuell).							Ich empfand das VR-Erlebnis als **angenehm** (körperlich, visuell).
Ich hätte **Hemmungen**, eine VR-Brille in einem Gespräch zu tragen.							Ich hätte **keine Hemmungen**, ein VR-Brille in einem Gespräch zu tragen.
Die Bewegung im virtuellen Raum mithilfe der **Viewpoints** (Blickwinkel) ist **nicht hilfreich**.							Die Bewegung im virtuellen Raum mithilfe der **Viewpoints** (Blickwinkel) ist **hilfreich**.
Die **Modelle** im VR-Modus sehen **unrealistisch** aus.							Die **Modelle** im VR-Modus sehen **realistisch genug** (für den Zweck) aus.
Kommentare							

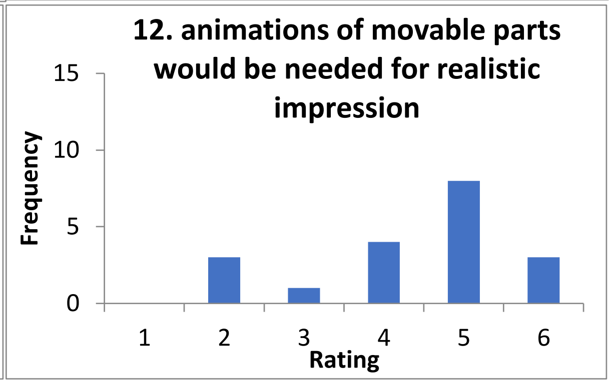
9.3.2. Histograms of questionnaire

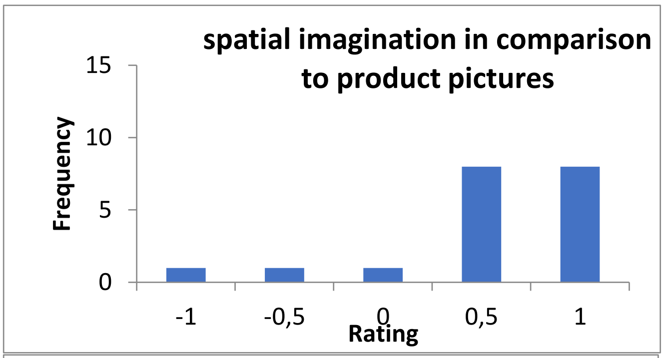


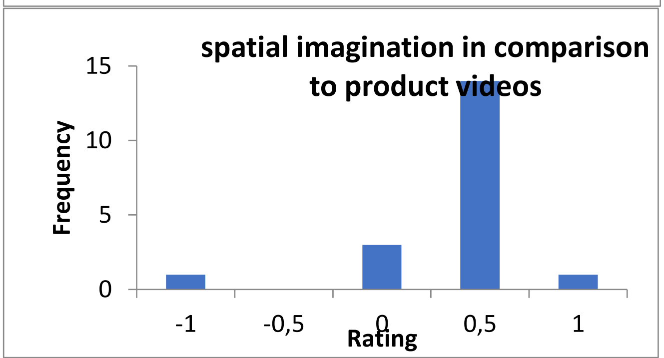

9. no inhibitions to wear a VR headset in dialog situations
Frequency
15
10
5
0
1
2
3
4
5
6
Rating

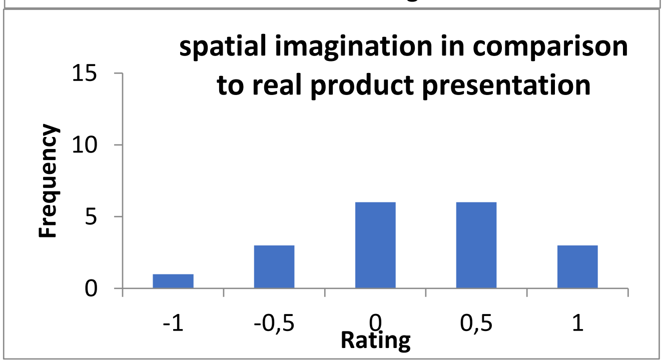

10. VR position control through viewpoints helpful
Frequency
15
10
5
0
1
2
3
4
5
6
Rating


11. models look realistic enough (for that purpose)
Frequency
15
10
5
0
1
2
3
4
5
6
Rating


12. animations of movable parts would be needed for realistic impression
Frequency
15
10
5
0
1
2
3
4
5
6
Rating


spatial imagination in comparison to product pictures
Frequency
15
10
5
0
-1
-0,5
0
0,5
1
Rating


spatial imagination in comparison to product videos
Frequency
15
10
5
0
-1
-0,5
0
0,5
1
Rating


spatial imagination in comparison to real product presentation
Frequency
15
10
5
0
-1
-0,5
0
0,5
1
Rating