HomePlanAR: Smart Dynamic Guides for Space Planning in Handheld Augmented Reality

Master Thesis

submitted by

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Abstract

Space planning is the activity of creating layouts for living spaces. It is a domain well-suited for augmented reality (AR) and some commercial applications like IKEA Place exist that implement this. However, they do not support the precise creation of layouts well and do not incorporate the pre-existing environment beyond detecting a ground level. Research into the support of space planning and 3D layout creation is sparse. This thesis introduces two techniques to assist space planning in AR: **Smart dynamic guides**, a technique for making alignments and measurements well-known from presentation software such as Microsoft PowerPoint, and a **scaleable grid system**. For this purpose, it presents a general overview of both foundations of 3D manipulation and current research into AR layout planning. It then documents the design and implementation of an application that uses both of these techniques and presents a study that was conducted as a usability test for the application. The data collected in this study was subjected to the method of thematic analysis. From the results of this study, it derives ideas that could improve the design of both techniques, such as adding transparency to avoid visual obstruction issues, and places them in the context of existing research. Finally, it gives an outlook on potential future research.

Contents

Abstract i

Contents ii

List of Figures iii

List of Tables iv

1. Introduction 1

2. Foundations 4
   2.1. Mixed Reality . . . 4
   2.2. 3D Object Manipulation . . . 5
   2.3. Layout Assistance Techniques . . . 7

3. Related Work 10
   3.1. Constraint Extraction for AR . . . 10
   3.2. Alignment in AR . . . 11
   3.3. Summary . . . 11

4. Prototype: *HomePlanAR* 12
   4.1. Design Process . . . 12
   4.2. Application Documentation . . . 13

5. Usability Study 19
   5.1. Research Questions . . . 19
   5.2. Study Design . . . 19
   5.3. Data Collection and Analysis . . . 23
   5.4. Results . . . 25
   5.5. Discussion . . . 32

6. Conclusion 39

References vii

A. Interview Codes viii

B. Interview Extracts xi

C. Study Documents xv

D. Enclosure xxii

List of Figures

1.1. *HomePlanAR* offers smart dynamic guides and a scaleable grid . . . 1
1.2. Smart dynamic guides in Microsoft PowerPoint . . . 2
1.3. Alignment grid in ArchiCAD . . . 3

2.1. The virtuality continuum . . . 4
2.2. Selection/de-selection in 'Collaborate!' . . . 5
2.3. Rotation in 'Collaborate!' . . . 6
2.4. Translation in 'Collaborate!' . . . 6
2.5. Equidistant alignment in Keynote . . . 7
2.6. Smart dynamic guide-like functionality in ArchiCAD. . . . 8
2.7. Studio 2.0 interface with grid visualization . . . 8

3.1. Automatically generated race track layout . . . 10
3.2. Object placement and creation in Nuernberger et al.'s study . . . 11

4.1. Schematic of the design process . . . 12
4.2. Early sketch of an AR smart dynamic guide concept. . . . 14
4.3. *HomePlanAR* UI . . . 14
4.4. *HomePlanAR* catalog . . . 15
4.5. Rotation and translation in *HomePlanAR* . . . 15
4.6. *HomePlanAR* smart dynamic guides . . . 16
4.7. Schematic of alignment detection in a top-down view. . . . 17
4.8. Vuforia Area Target used for *HomePlanAR* . . . 17
4.9. Rotation on the scaleable grid . . . 18
4.10. Set of objects available in *HomePlanAR* . . . 18

5.1. Reconstruction phase floor plan . . . 21
5.2. The mixed reality lab, seen from the researcher's desk. . . . 22
5.3. Work-in-progress candidate theme clusters on a digital whiteboard . . . 24
5.4. SUS questionnaire results . . . 25
5.5. Comparion of mean ratings per technique . . . 26
5.6. Interview rating of the grid technique per task . . . 26
5.7. Interview rating of the smart dynamic guide technique per task . . . 27
5.8. Final state of the digital whiteboard used to determine themes. . . . 28
5.9. P1's confirmation UI sketch . . . 31
5.10. Visualization of how a measuring tool could display distances between non-aligned objects. . . . 35
5.11. Transparent active object . . . 35
5.12. Alternating color grid lines in *HomePlanAR* . . . 36

List of Tables

5.1. Guided phase catalog 20
5.2. Reconstruction phase catalog 20
5.3. Free phase catalog 21

A.1. Interview codes viii
A.2. Interview codes continued ix
A.3. Interview codes continued x

1. Introduction

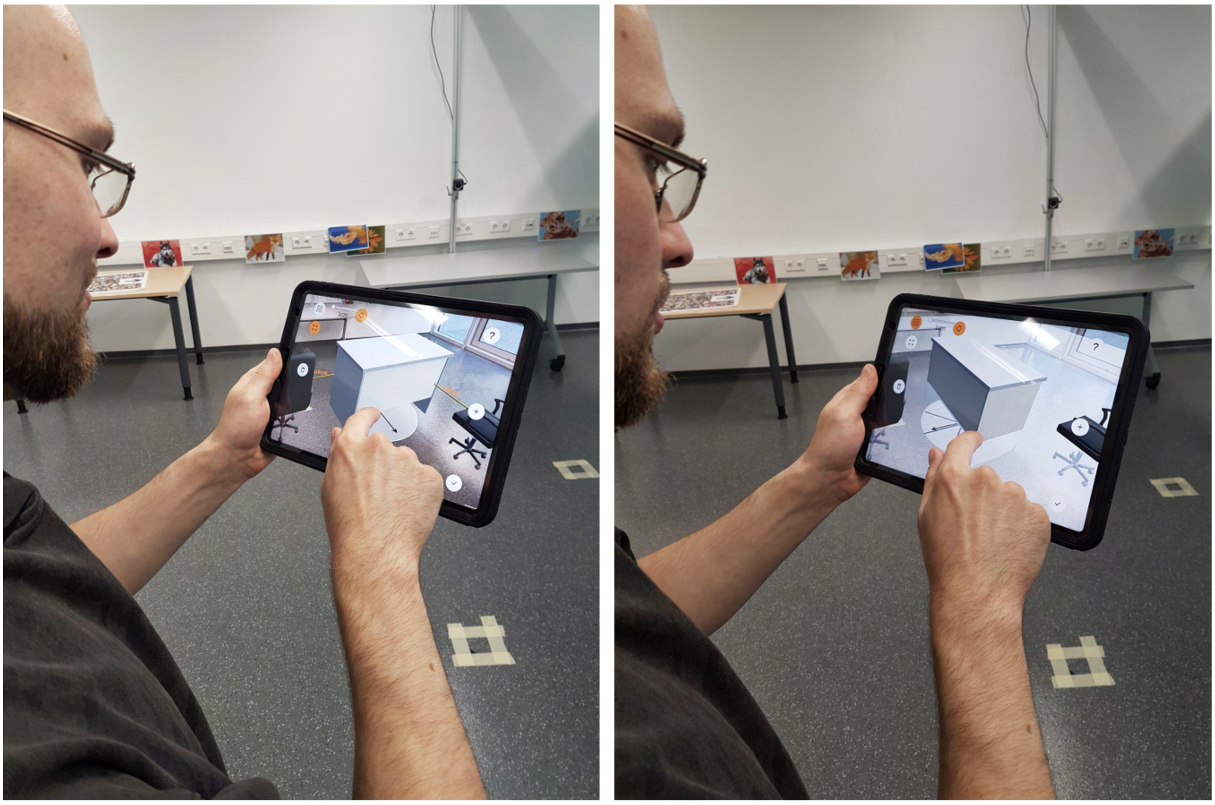

Figure 1.1.: *HomePlanAR* offers smart dynamic guides (left) and a scaleable grid (right).

Space planning is a deeply human activity. As a behavior, it can be seen even in the traces our earliest ancestors left behind in the natural spaces they inhabited and shaped for their needs and preferences [1]. Today, with ever-shrinking urban living spaces and near-limitless choices of mass-produced items to furnish those spaces with [2], it is perhaps a more complex task than ever. At the same time, new technologies are emerging that can assist people in novel ways. Powerful depth sensors can produce accurate spatial maps for any room [3, 4]. Augmented Reality (AR) can use this to place virtual objects realistically in physical environments.

What the term space planning describes, is the activity of placing objects in a pre-existing space to make it fit for a purpose, for example as a living room or office. At its core, it is a type of layout task. Tools for layout tasks are common, with programs like Microsoft Powerpoint [5, 6, 7] being widely distributed and used. In these programs, some techniques can be found that have been established to assist in these layout tasks. Furthermore, there also is some software that supports the creation of 3D layouts, like the computer-aided architectural design program ArchiCAD [8, 9], which implements many of the same techniques.

As a special case of 3D layout creation, space planning has some features that differentiate it from general 3D layout creation. In general 3D layout creation, objects can be moved freely in all directions and rotated into every possible orientation. In space planning, every object is instead attached to a plane. This is, for example, the ground on which a chair stands or the wall to which a picture is attached. This has the effect that objects can only be moved and rotated in relation to their parent plane. It still is a special case of 3D layout creation rather than a different way to display 2D layout creation, though, because arrangements are made between the planes found in the room (floor, ceiling, any wall).

Space planning in AR has not yet implemented many of the learnings from existing layout software. Interior design applications like IKEA Place [10] use AR primarily as a method of 3D visualization and novel way to view 3D models. They offer limited or no ways to plan the integration of AR content into the real environment. However, space planning in real-life scenarios is often performed in partly furnished rooms, so integrating existing physical objects into the process can yield great benefits.

In this thesis, two techniques are introduced that can improve AR space planning software: Smart dynamic guides and a scaleable grid. These are derived from existing space planning and 3D layout software.

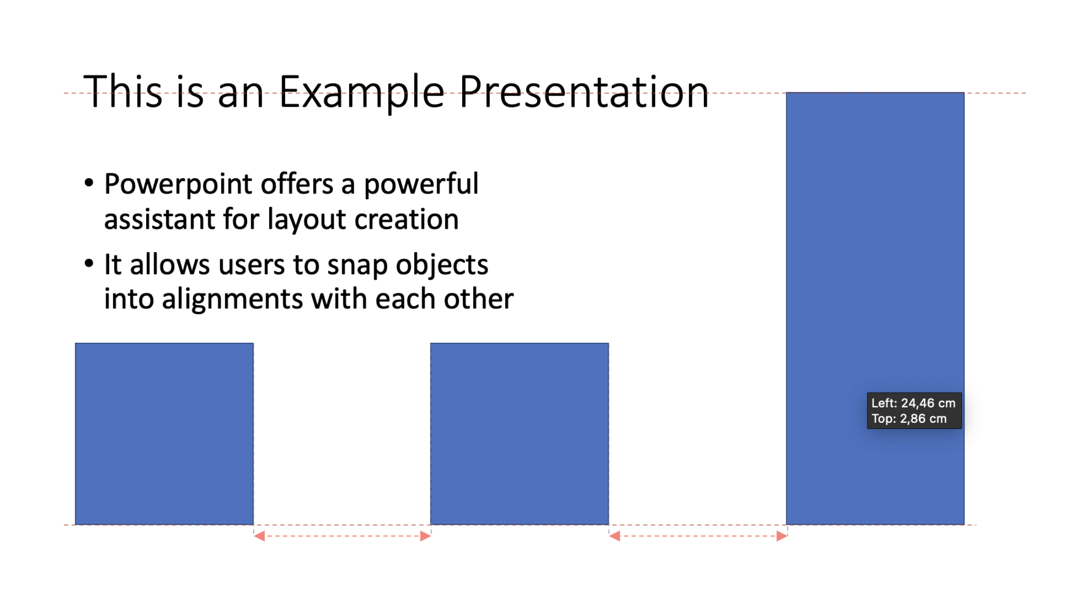

Figure 1.2.: Smart dynamic guides in Microsoft Powerpoint [5] allow the user to arrange components on a slide with each other. Here the top of the rectangle on the right is aligned with the centerline of the heading text and the bottom of it is aligned with the bottoms of the smaller squares. The distance between the rectangle and the right square is equal to the distance between both squares. The alignments are shown with red lines and distances with arrows, which constitute the smart dynamic guides.

Smart dynamic guides are commonly found in presentation software (see figure 1.2). There they automatically detect possible alignments between objects when one of the objects is being moved. The object then snaps into those alignments, and they are visualized by showing smart dynamic guides.

The other method of layout assistance introduced here, a grid system, is often found in 3D editors (see figure 1.3). In grid systems, objects snap to features of the grid, typically the grid lines or the intersections of those lines.

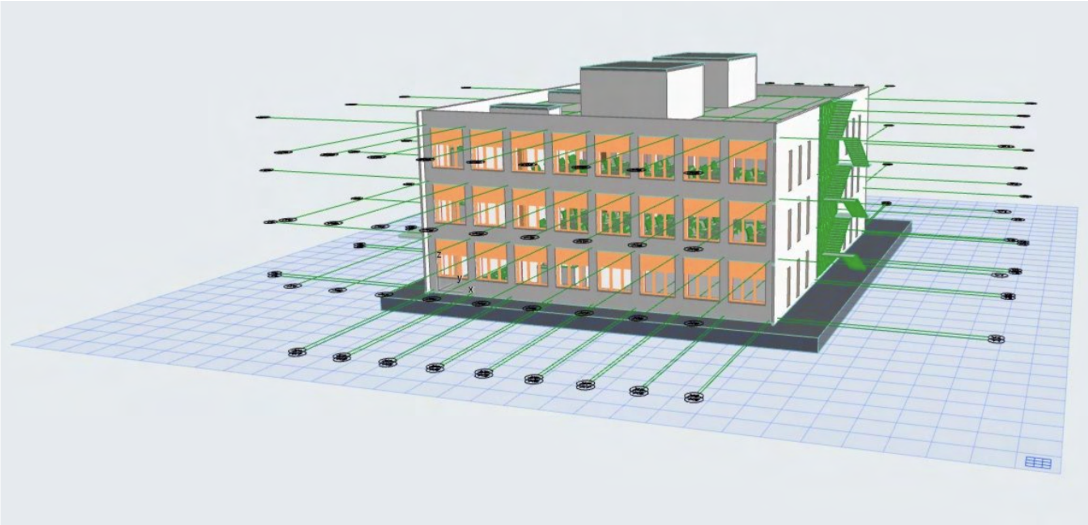

Figure 1.3.: Alignment grid in ArchiCAD [8]. When enabled, users can use a 3D grid to position objects and shapes. Figure taken from [11].

The grid system presented in this thesis is scaleable to allow users to make it conform to their needs relating to the environment.

This thesis first provides an introduction to the foundations of AR, 3D manipulation, and the basic concept of both layout assistance techniques. It then summarizes the design and implementation of a prototype for AR space planning that features both of these techniques. This prototype was evaluated in a user study. The study and its results are presented here, and their implications for design improvements and future work are discussed.

2. Foundations

This chapter provides a brief introduction to mixed reality and an overview of the foundations of 3D object manipulation. It also introduces techniques that assist in layout tasks.

2.1. Mixed Reality

In human-computer interaction research, mixed reality is a term describing part of a spectrum of virtuality. Paul Milgram and Fumio Kishino describe this as a "virtuality continuum" [12]. This continuum has the unaltered real environment on one end and a completely virtual environment on the other end. Everything in between, where virtual and physical objects are simultaneously present, is categorized as mixed reality (see figure 2.1). Milgram and Kishino describe two principal categories within MR: Augmented virtuality (AV) as a primarily virtual environment, which is being augmented through the use of real objects and augmented reality (AR) as a real environment, which is being augmented through the use of virtual objects.

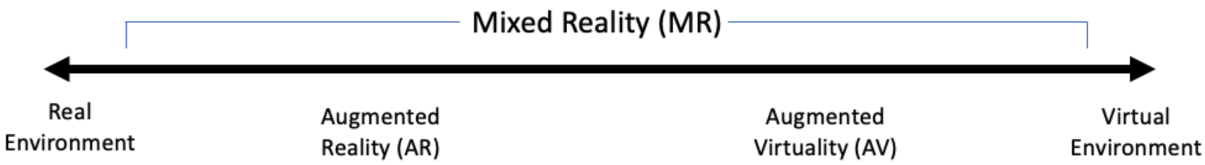

Figure 2.1.: The virtuality continuum described by Milgram and Kishino, figure recreated from [12].

The potential MR has for space planning is evident in the ability to use the real environment to reduce the abstraction needed to plan. For this thesis, AR is therefore the most relevant part of the MR spectrum. The two most prevalent technologies to implement AR currently are head-mounted displays (HMDs) and handheld AR using a smartphone or tablet.

AR using HMDs can be accomplished either by using semi-transparent displays which overlay virtual content over an unaltered view of the real environment or by using see-through displays which combine a solid display with a front-facing camera and embed the virtual content in the camera stream. An example of the former is the Microsoft Hololens [13]. See-through devices are less common but, for example, the Varjo XR-3 [14] implements this concept. With either technology, the augmented reality view is directly overlayed onto the user's vision, supporting their stereoscopic vision.

Handheld AR functions in a similar way to see-through HDMs, where the front-facing camera on a mobile device, such as the iPad Pro 2021 [3], captures a video feed of the physical environment, into which virtual objects are injected and displayed on the device's screen. The screen functions as a window into the augmented reality view.

As Mark N. Billinghirst and Anders Henrysson outline in their 2006 publication "Research Directions in Handheld AR," [15] interaction paradigms differ greatly between head-mounted and handheld AR. HMDs leave the user's hands free to perform unrestricted two-handed interactions, but have some limitations to their input utilities, often relying on gesture controls. This is sometimes addressed through the use of hybrid user interfaces [16], which represent an area of research of their own. Handheld devices on the other hand do allow for the application of many familiar touch interactions [17].

Another factor dividing these two approaches is the distribution of devices. AR HMDs are still restricted to enterprise and research applications and are rarely found in the consumer market. AR-capable smartphones on the other hand have become the norm among new devices [18].

This thesis focuses on the use of handheld AR to utilize well-established methods of 3D object manipulation on flat screens.

2.2. 3D Object Manipulation

The literature concerning 3D object manipulation has settled on four canonical tasks: Selection/de-selection, rotation, translation, and scaling [19, 20, 21]. Selection/de-selection is the activity of beginning or ending the manipulation of one or more objects. Rotation is the manipulation of the three degrees of freedom (DoF) of an object's orientation. Translation is the manipulation of the three DoF of an object's position. Scaling is the manipulation of an object's dimensions. Of these tasks, only the first three are typically relevant to space planning, as pieces of furniture usually come in set sizes.

Jonathan Wieland et al. presented a system, dubbed 'Collaborate!' [22], that supports the space planning scenario in handheld AR for their research into collaborative 3D object manipulation [23]. This system implements the three 3D manipulation tasks relevant to the space planning scenario. The following sections will detail each of the canonical tasks and, where appropriate, present their implementations for handheld AR space planning used by Wieland et al.

2.2.1. Selection/De-Selection

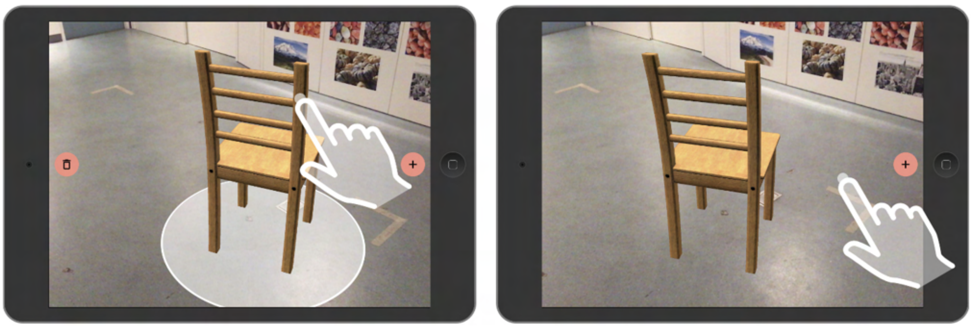

Figure 2.2.: In the 'Collaborate!' prototype, a white plate highlights selected objects. Objects are selected by a touch input targeting them, and de-selected with a touch input elsewhere in the scene. Figure taken from [22].

A well-established method of selection in 2D user interfaces is pointing at an object and providing an input to confirm the selection. In a mouse-pointer interface, this is accomplished with a click. This can for example be seen in the Unity editor [24]. On a touch interface, the user can usually touch the target. This method was used in the 'Collaborate!' prototype [22]. When an object is selected, the selection is displayed to the user, often through outlines or by adding visual elements (see figure 2.2). Finally, de-selection is accomplished in one of two ways, either implicitly through the selection of a new object, or explicitly. The 'Collaborate!' prototype supports both methods, with explicit de-selection being accomplished with a touch input on an empty part of the scene.

2.2.2. Rotation

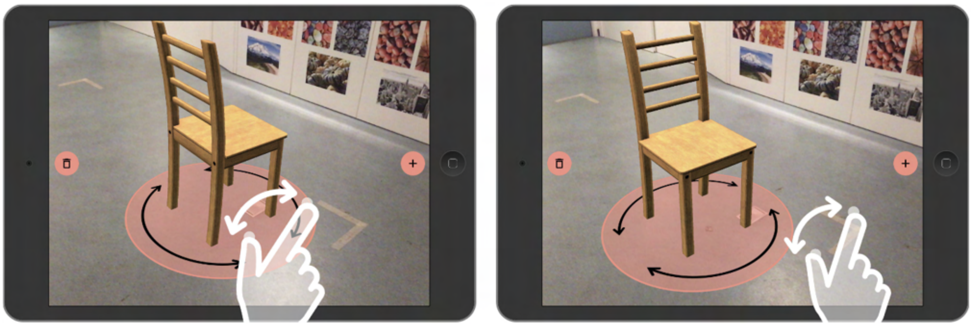

Figure 2.3.: In the 'Collaborate!' prototype, objects can be rotated using a familiar two-finger gesture. Figure taken from [22].

On 2D user interfaces, manipulation is often decomposed to be performed individually for each DoF [25]. For the space planning scenario, this is simplified even further, as objects can only be rotated around the normal vector of the plane they are attached to. This single-DoF manipulation is performed with a two-finger gesture in the 'Collaborate!' prototype [22] (see figure 2.3). This can be performed anywhere on the screen.

2.2.3. Translation

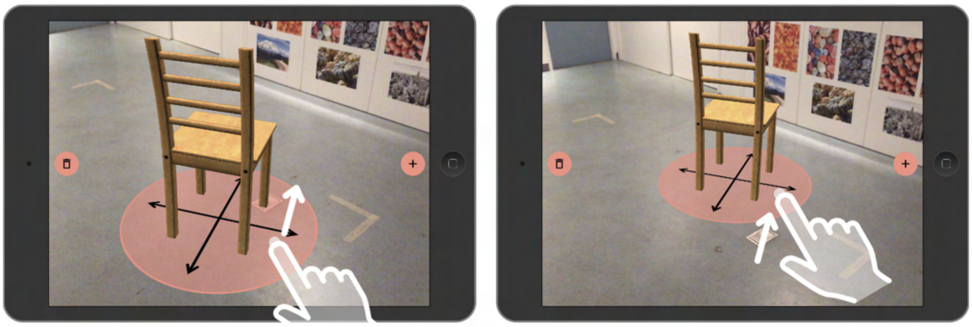

Figure 2.4.: In the Collaborate prototype, objects can be moved with a touch-and-drag gesture. Figure taken from [22].

Translation is a similar case to rotation, where in praxis the manipulation is often decomposed into single-DoF manipulations. Again space planning simplifies this further, as objects can only be moved along two DoFs on the plane they are attached to. In the 'Collaborate!' prototype, this is accomplished with a touch-and-drag interaction [22] (see figure 2.4).

2.2.4. Scaling

Scaling is not as relevant to the space planning scenario, as it describes the distortion of objects along their three primary axes. 2D interfaces again typically decompose this task into three individual manipulations for each axis.

2.3. Layout Assistance Techniques

This section presents two methods of assisting in the creation of layouts: Smart dynamic guides and grid systems. It uses examples of existing software products to do this.

2.3.1. Smart Dynamic Guides

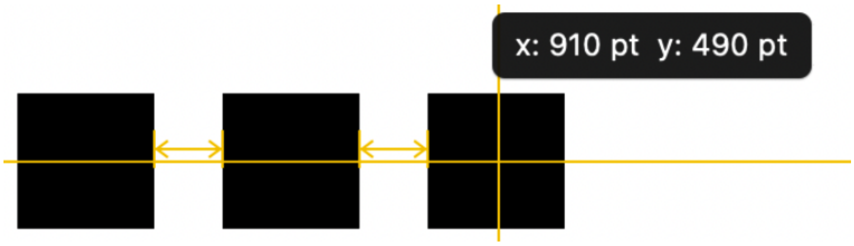

Figure 2.5.: Equidistant alignment of three squares in Keynote [7]. The right square is being moved so that its center line is aligned with the centerlines of both other squares. Its distance to the middle square is equal to the middle square's distance to the left square. The right square is also aligned with the center of the slide. Figure taken from [26].

Smart dynamic guides is a term coined by Microsoft to describe the system of layout assistance present in PowerPoint [5]. The concept is, however, not unique to their products and has become a standard feature of software for 2D layout creation [6, 7]. Smart dynamic guides modify how objects are moved in relation to their environment. When an edge or the center line of the object that is being moved is aligned with another object in the layout, it snaps into that position and a guide is displayed. Distances to and between other objects are also detected. When an object is put into a position, where it has distances equal to some other objects, it also snaps into that position (see figure 2.5).

The technique has also been used in the context of 3D layout editors, where it functions in the same way, with alignments being searched for in all directions from the object that is being manipulated. An example of this is the computer-aided architectural design program ArchiCAD [8] (see figure 2.6).

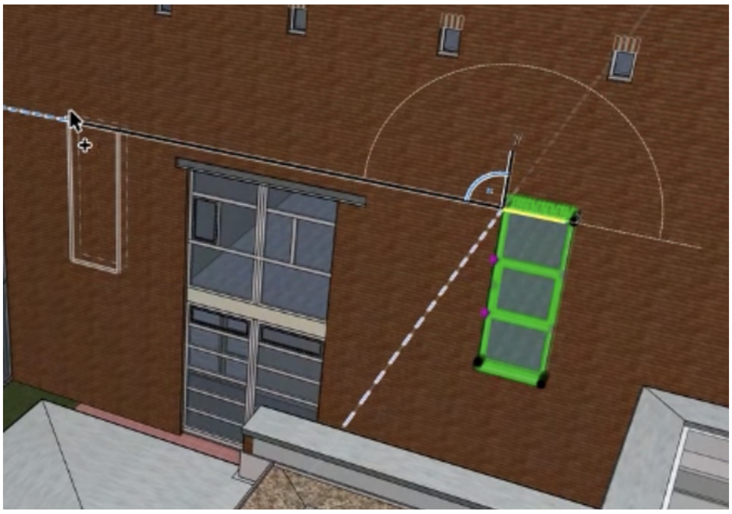

Figure 2.6.: Smart dynamic guide-like functionality in ArchiCAD [8]. Figure taken from [26].

2.3.2. Grid Systems

An alternative technique to support the creation of layouts is the use of a grid upon which objects are moved. Objects are moved according to a grid logic across cells, bordered by the grid lines, or nodes, formed by the intersections of grid lines. This allows users to align objects along the grid lines.

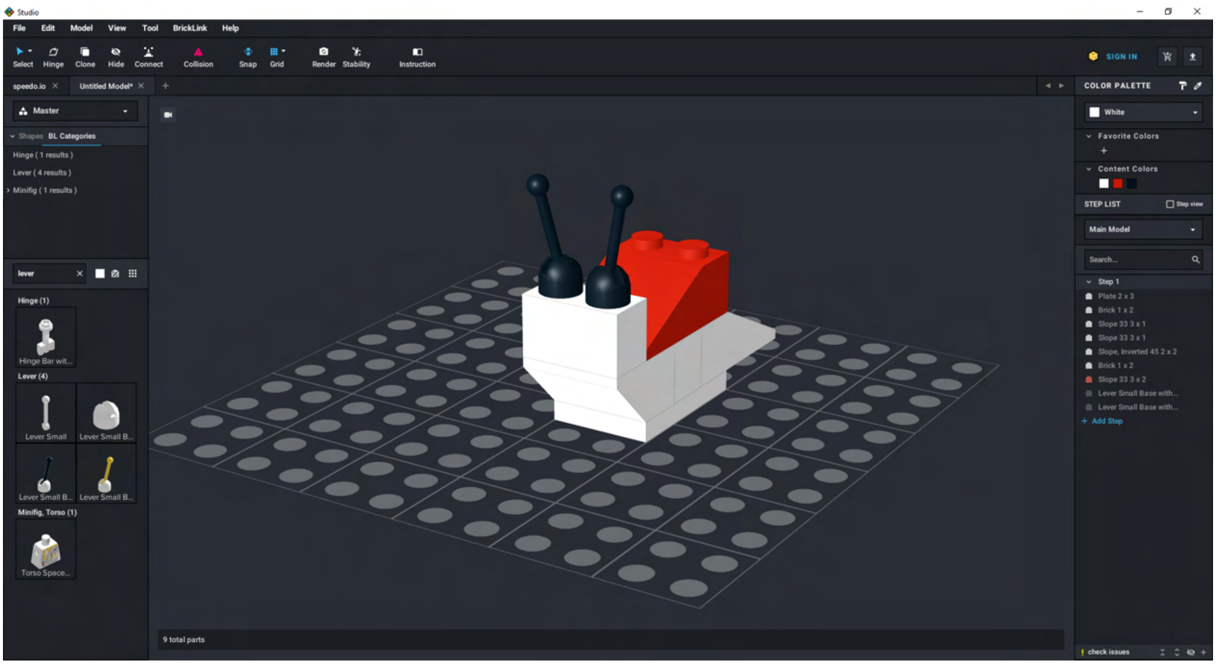

Figure 2.7.: Studio 2.0 [9] interface with grid visualization seen at the ground level. The snail model was created as a product of the tutorial included in the software. Figure taken from [26].

This can, for example, be seen in Studio 2.0 [9], the 3D editor used by the LEGO Group to digitally design toy sets using their system of plastic bricks. LEGO uses the dimensions of attachment points on their bricks, one "stud", as a unit of measurement for their parts. Studio 2.0 has a grid, which by default has cells with the dimensions of one-eighth of a "stud" cubed (see figure 2.7). This can be adjusted to be more or less precise. It can also be disabled for completely free placement.

3. Related Work

This chapter presents the state of research toward alignment assistance and layout creation incorporating the physical space in AR. First, it summarizes methods of processing the space. Then, a system offering some of the characteristics of smart dynamic guides is introduced.

3.1. Constraint Extraction for AR

The basis for alignment assistance in AR that incorporates the physical space is understanding which features of the space can be used to make alignments. These features are typically termed constraints [27]. In their 2014 publication "FLARE: Fast Layout for Augmented Reality Applications," [28] Ran Gal et al. described a method of extracting the constraints of a space and automatically fitting a layout into that space. They demonstrated this on the example of a race track that was automatically generated and fitted to the room (see figure 3.1). The primary features they identified as constraints are planes and edges. For their research, they used a Microsoft Kinect depth camera, processing the spatial data with KinectFusion [29].

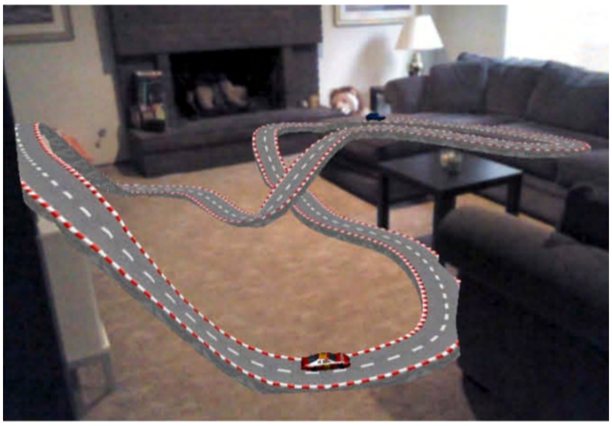

Figure 3.1.: Automatically generated race track layout using the FLARE system. The track conforms to planes and edges detected in the room. Figure taken from [28].

This assessment of planes and edges being the dominant constraints is shared by Ke Huo et al. in their 2016 publication "Window-Shaping: 3D Design Ideation in Mixed Reality" [30]. In it, they present a handheld AR 3D sketching tool that allows users to add to physical objects by making 2D drawings over those objects. The system then extracted the underlying constraints and created a new 3D object fitting the drawn shape to those.

3.2. Alignment in AR

The topic of user-created aligned content in AR is a lot less prevalent in current research than the creation of automatically generated layouts as described in [28]. The term "smart dynamic guides" is also not being applied to AR, yet. There is however some research into the creation and visualization of alignments between user-created content with real-world constraints conducted by Benjamin Nuernberger et al. in 2016 [27].

Nuernberger et al. presented the design, implementation, and evaluation of a system for object placement and creation. Objects could snap directly to edges and planes. When shaping objects, shapes snapped to nearby constraints (see figur 3.2). Their application used a see-through HMD.

In their study, they used two tasks, in which participants had to dock objects to ghost images. First, they had to place windows in target locations. Then, they were asked to create shapes conforming to targets. The independent variable in their experiment was whether snapping was supported in the application. Nuernberger et al. found benefits for snapping both in efficiency and reported user experience.

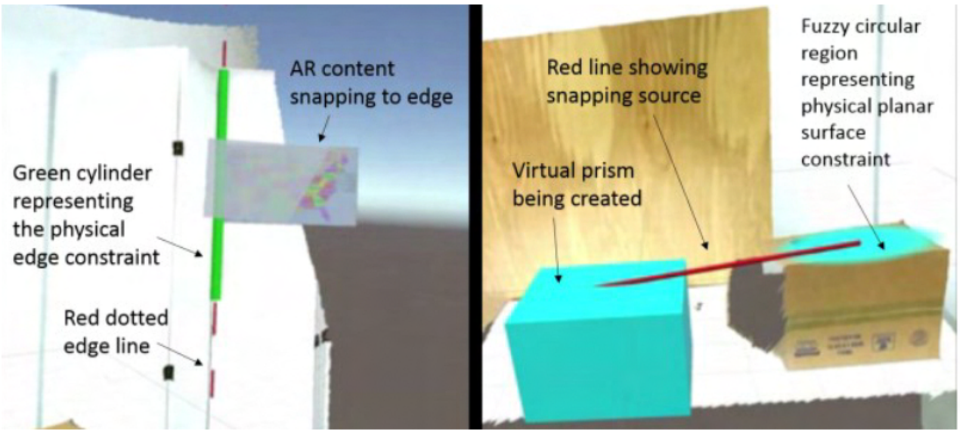

Figure 3.2.: Object placement (left) and creation (right) in Nuernberger et al.'s study. In both scenarios, the constraints that are being snapped to are visualized as described in the figure. Figure taken from [27].

The visual indicators used by Nuernberger et al. have some similarities with smart dynamic guides. Nuernberger et al. emphasize the importance of clearly displaying which constraints impact an object when using snapping.

3.3. Summary

Research concerning user-created 3D layouts in AR is sparse. Research on the architectural space planning scenario typically focuses on presentation purposes [31]. However, the definition of constraints in the context of AR layouts provided by Gal et al. [28] and some of the visualizations made by Nuernberger et al. [27] provide a basis for user-created layouts and the design of smart dynamic guides for AR.

4. Prototype: *HomePlanAR*

As the project for this thesis [32], an application implementing the concepts discussed in 2.3 was created. This chapter provides a detailed overview of the prototype, named *HomePlanAR*, and its development. The prototype enables users to browse a selection of furniture items, place those items in the real environment, and arrange them. Users are given two options for arrangement assistance: Smart dynamic guides and a scaleable grid. It also guides participants through a user study by displaying tasks.

The prototype was built in Unity Engine 2020.3.29f1 [24], with AR technology provided by Vuforia Engine AR 10.7.2 [4].

4.1. Design Process

This section summarises the design process that was performed as a part of the project for this thesis. The process was planned to fit into the agile UX lifecycle model [33] (see figure 4.1).

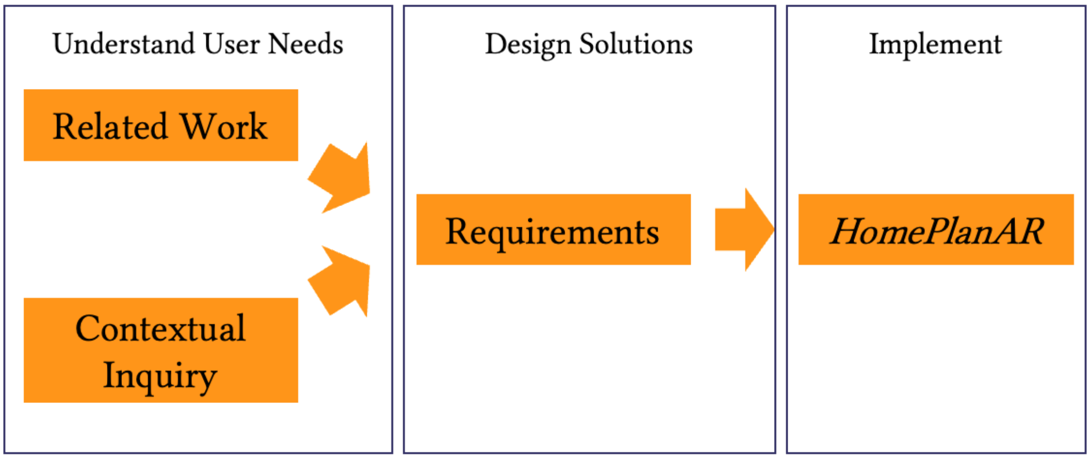

Figure 4.1.: Schematic of the design process. The process was planned according to the UX lifecycle model [33]. It begins with a phase of understanding user needs, followed by the design of solutions to help these needs, followed by the implementation of a prototype to evaluate those solutions. Figure taken from [32].

In the design process, a list of requirements was derived from the literature and software summarized in 2 and 3. These requirements are presented here, taken and updated from [32]. **R1** through **R5** concern the basis of object manipulation, **R6** through **R9** the implementation of smart dynamic guides, and **R10** through **R12** the implementation of the grid system and the interplay between the systems.

R1 Instantiation: The user must be able to select and place new objects in the environment.

R2 Selection and Release: The user must be able to select objects they intend to manipulate. They should also be able to release their selection.

R3 Translation: The user must be able to re-position a selected object in the room.

R4 Rotation: The user must be able to rotate a selected object.

R5 Deletion: The user must be able to remove a selected object from the environment.

R6 Snapping: Objects should snap into significant alignments when manipulated.

R7 Arrangement: Objects should snap into equidistant arrangements when multiple objects are aligned with each other.

R8 Constraint Visualization: Guides must clearly indicate which constraints cause a snapping behavior.

R9 Distance Visualization: Guides must encode the distance between objects.

R10 Grid Alignment: Objects should snap to a grid when being moved around.

R11 Grid Scaling: The user must be able to scale the granularity of the grid.

R12 Grid Rotation: The user must be able to fit the grid's orientation to their needs.

R13 Alignment Customization: The user must be able to freely choose which methods of alignment are being applied at any given moment.

To inform the design decisions, especially concerning the implementation of smart dynamic guides, a focus group interview was conducted remotely as a contextual inquiry. Five participants were invited, all of them students from the disciplines of psychology ($n = 3$), computer science ($n = 1$), and architecture ($n = 1$). Three identified as female and two as male.

The focus group was planned according to guidelines laid out by Richard A. Krueger et al. [34]. In the interview, participants were asked about their space planning habits. For this, they were instructed to look for alignments in the rooms they inhabited. They were also asked about their experiences with 2D layout software, and finally about how they could envision the proposed techniques assisting them in space planning.

Design solutions for smart dynamic guides and the scaleable grid in AR were then developed, using VR 3D sketching software (see figure 4.2). Finally, a functional prototype was implemented. The full process and technical implementation was documented in the project report for this thesis [32].

4.2. Application Documentation

This section presents the final state of the prototype's interface and features.

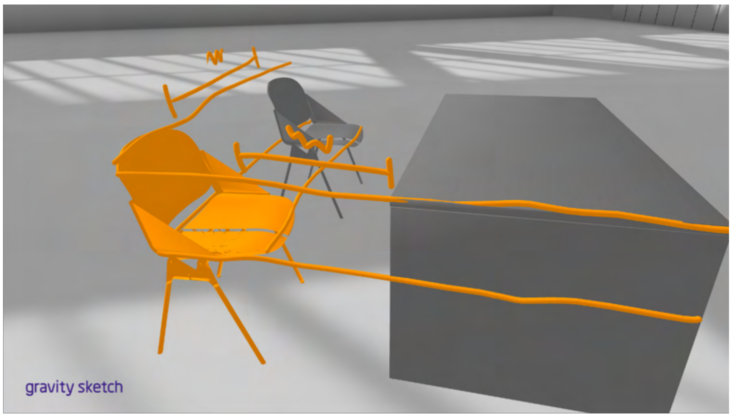

Figure 4.2.: Early sketch of an AR smart dynamic guide concept. The grey objects represent physical objects and the orange object represents an object that is actively being manipulated. Lines mark the full lengths of the aligned constraints and an additional line with whiskers on both ends displays the distance. Figure taken from [32].

4.2.1. User Interface

The prototype's user interface builds on the interface used for 'Collaborate!' by Wieland et al. [23] It offers the same functionality for browsing, placing, deleting, and manipulating furniture, satisfying **R1** through **R5** (see figures 4.3, 4.4, 4.5). Furthermore, it enables users to choose between or deactivate the alignment assistance modes (**R13**). Users can also scale the grid using a slider (**R11**), and re-adjust it to selected furniture using a button (**R12**). The methods of object manipulation are taken from 'Collaborate!' [23] and have been adjusted to also work with items that are attached to another plane than the ground plane to accommodate pictures.

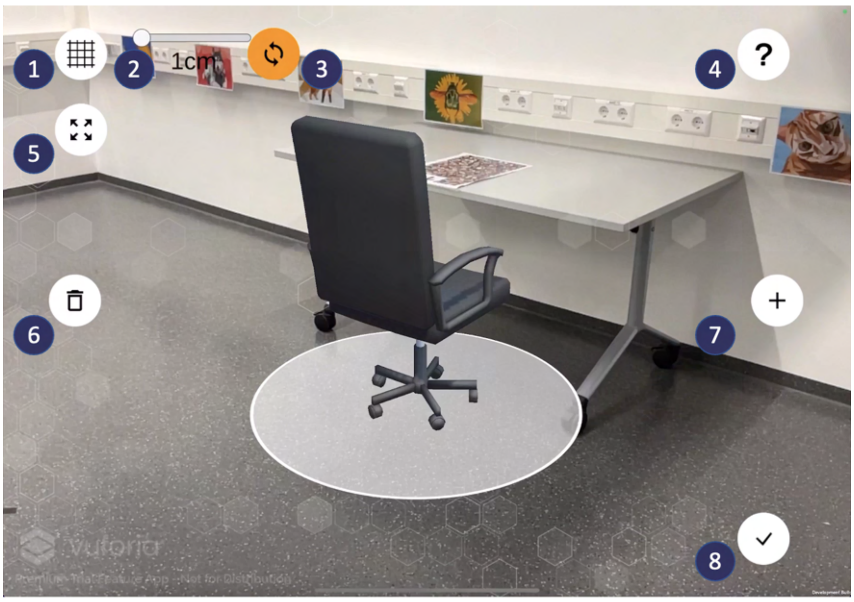

Figure 4.3.: *HomePlanAR* UI. (1) Switch to or deactivate grid; (2) scale grid; (3) align grid with selection or reset to default position; (4) open current study task; (5) switch to or deactivate smart dynamic guides; (6) delete selection; (7) open catalog; (8) confirm study task completion.

One addition to the method of selection compared to 'Collaborate!' is that with *HomePlanAR*, users can select and manipulate multiple objects simultaneously. To do this, the user can engage a multiselection mode through a long press on the active object. The activation of this mode is indicated by a clicking sound. Any further object they then touch is added to the selection. If they touch an empty part of the scene as they would for de-selection, the mode is ended and touching a different object changes the selection. This is again indicated by a different clicking sound.

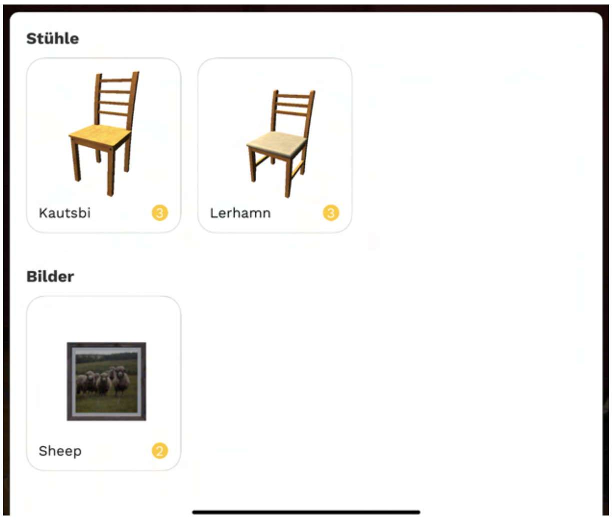

Figure 4.4.: *HomePlanAR* catalog. When the user taps an item, that item appears in front of them. They can browse the catalog by scrolling. The number on each item indicates the remaining quantity of that item. This element is identical to the 'Collaborate!' system [23]. Figure taken from [32].

Figure 4.5.: Rotation (left) and translation (right) in *HomePlanAR*. They function identically to the same interactions in 'Collaborate' [23], as described in 2.2.2 and 2.2.3, with the exception of the interactions also being possible for pictures.

4.2.2. Alignment Assistants

HomePlanAR provides two modes of alignment assistance, smart dynamic guides and a scaleable grid. These modes each add visualization to the app and modify how objects can be manipulated. Users can activate one of the modes at a time or choose to use neither depending on their needs and preferences.

Smart Dynamic Guides

The smart dynamic guides in HomePlanAR are designed to add minimal visual clutter to the scene. They consist of a line with whiskers on either endpoint and a distance display, which always faces the AR camera to enhance readability.

Figure 4.6.: *HomePlanAR* smart dynamic guides appearing between two aligned virtual and physical tables.
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When a furniture object is selected as the active object, rays are continually cast away from each of its edges. If such a ray hits an aligned edge of another piece of furniture, a smart guide is displayed between the origin and point of detection (see figure 4.7). The hit object then polls for further aligned objects along the same axis of alignment and searches for other aligned objects at the same distance as it has with the selected furniture object in the same way This is then repeated, finding all equidistant alignments. When two or more edges are aligned, the manipulation of the active object is restricted. If there is only one other object aligned, the active object sticks to the axis of alignment. All movements, whose component vector running perpendicular to the axis of alignment is smaller than a threshold of 5cm, are projected onto the axis instead of breaking the alignment Effectively, this allows the user to change the distance between both objects freely without changing the alignment. When, in addition to this, equidistant alignments with further objects on another axis are detected, the active object instead sticks to its present position.

The constraints of the objects, both physical and virtual, were manually modeled on the objects. For the physical objects, this was accomplished using a Vuforia Area Target. This is a 3D scan of the room that can be used by

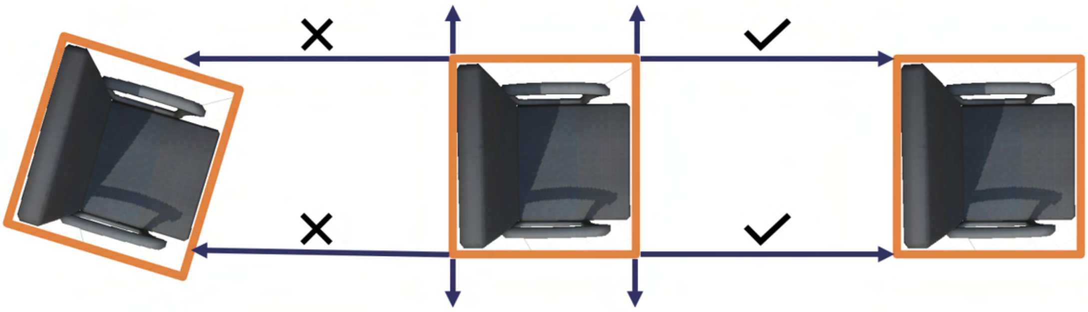

Figure 4.7.: Schematic of alignment detection in a top-down view. The center chair is being manipulated and casts rays to detect other objects from each of its constraints. The right-hand chair is found to be aligned, therefore smart dynamic guides will be displayed. The left-hand chair is not aligned.

the AR device to orient itself (see figure 4.8). The application can use this data to position virtual objects in the environment. Constraint objects were placed on every manually determined constraint of the scene.

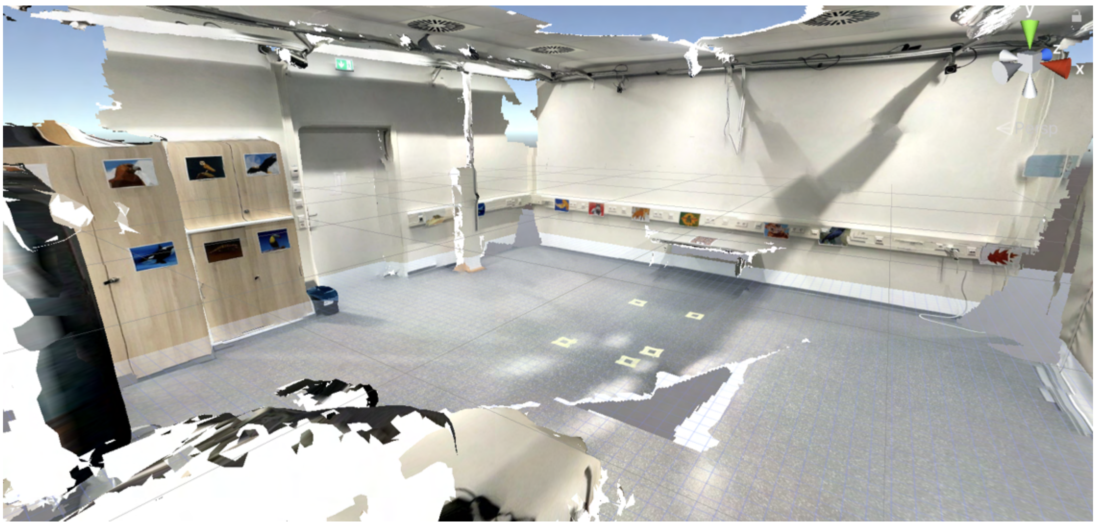

Figure 4.8.: Vuforia Area Target used for *HomePlanAR*, displayed in the Unity editor.

Scaleable Grid

The scaleable grid in *HomePlanAR* is displayed with semi-opaque blue lines 15cm above the ground level when enabled. When objects are moved, their position is projected to the next-nearest intersection of grid lines. When objects are rotated, they snap into eight possible 45° alignments along the grid. The possible alignments are displayed with four crossed lines that are shown on top of the rotation indicator (see figure 4.9).

By default, the cells of the grid have a size of 10cm. Using the UI slider, users can adjust this between 1cm and 100cm.

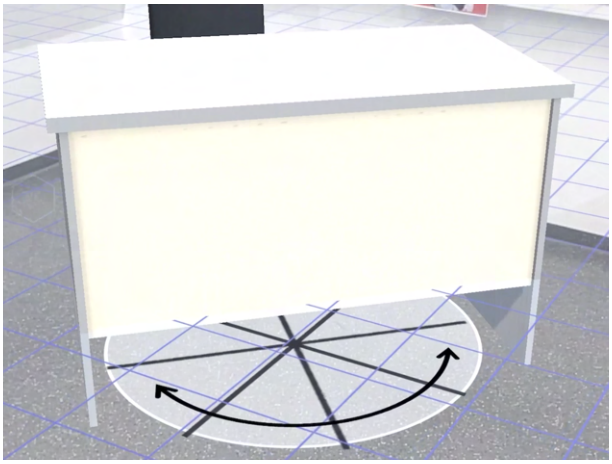

Figure 4.9.: Rotation on the scaleable grid. The blue lines near the ground level indicate the possible grid positions. The four crossed lines on the rotation indicator show which orientations are possible.

4.2.3. Catalog Items

The objects users can place with *HomePlanAR* are pre-produced assets that were either taken from 'Collaborate!' [23] or purchased from the Unity Asset Store [35, 36]. Each object had colliders fitted to its constraints. The full set of objects can be seen in figure 4.10.

Figure 4.10.: Set of objects available in *HomePlanAR*. (1) Office chair; (2) cupboard; (3) picture; (4) desk; (5) table; (6) armchair; (7) conference table.

5. Usability Study

The prototype *HomePlanAR* was designed and developed in one iteration of Rex Hartson and Pardha Pyla's agile UX lifecycle model [33]. The usability evaluation conducted for this thesis represents the final evaluation step of the cycle and aims to evaluate how successfully the techniques have been implemented. Burak Pak and Johan Verbeke affirm that the usability metrics Hartson and Pyla present are also relevant to computer-aided architectural design [37]. It furthermore aims to create insights into how the alignment techniques are used in a practical application, how the design choices made could be improved, and how these techniques can be integrated into the wider field of 3D manipulation and layout creation in AR.

5.1. Research Questions

The goals of this study can be summarised in three research questions:

RQ1: How can smart dynamic guides and the grid system support users with space planning in handheld AR?

RQ2: How are smart dynamic guides and the grid system used during space planning in handheld AR?

RQ3: How can the design of smart dynamic guides and the grid system be improved?

5.2. Study Design

The usability test was planned according to recommendations made by Rex Hartson and Pardha Pyla [38], to use the prototype for a high-level type of formative evaluation. Starting with a presentation familiarising them with the application through demonstration, participants first performed a set of tasks, after which a detailed interview was conducted. The study was conducted in German.

5.2.1. Tasks

The tasks for the usability test were organized in three phases: A guided phase intended to familiarize participants with all features of the system, a reconstruction phase where participants were handed a floor plan to recreate, and a free phase, where participants were asked to plan a room as they saw fit.

Guided Phase

The guided phase was divided into eight small tasks, chosen to prompt participants into applying the different tools offered in the app.

1. Place an office chair in front of the empty physical table.
2. Place a picture on the wall to the left of the empty physical table.
3. Align the left side of the picture with the right side of the empty physical table.
4. Place a virtual desk on the right next to the empty physical table.
5. Move the virtual desk to have the same distance from the empty physical table and the wall to its right.
6. Delete the picture.
7. Place another office chair in front of the virtual desk.
8. Move the new virtual office chair and the virtual table together to the left side of the empty physical table.

In this phase, the catalog (see table 5.1) had the pieces of furniture required for each sub-task available simultaneously to facilitate the participants getting used to the functionality and navigation of the catalog.

Furniture Item	Quantity
Office Chair	2
Picture	1
Desk	1

Table 5.1.: Guided phase catalog. Participants were instructed through the application to place and delete these items. Following the instructions completed the task.

Reconstruction Phase

In the reconstruction phase, participants were handed a printout of a floor plan of the room, with the real existing furniture demarked in white (see figure 5.1). In addition to this, four tables and five chairs are demarked in orange. The participant's task was to use *HomePlanAR* to place furniture items in AR to re-create the floor plan. The catalog (see table 5.2) only contained the relevant items in this phase.

Furniture Item	Quantity
Office Chair	5
Desk	4

Table 5.2.: Reconstruction phase catalog. Participants had to place each item according to the floor plan to complete the task.

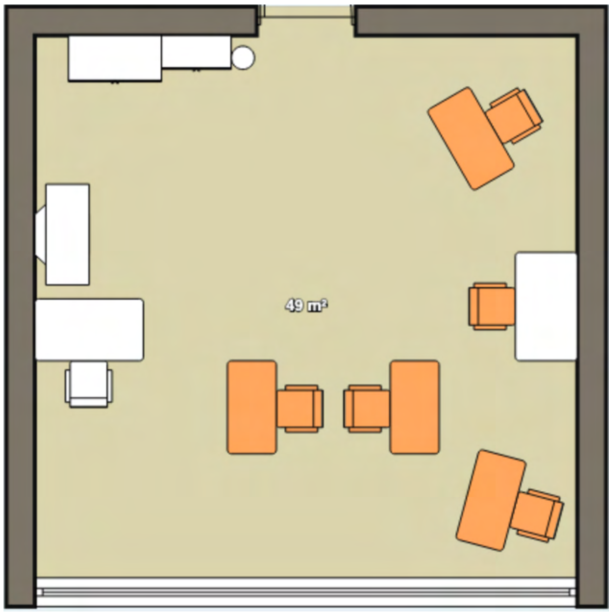

Figure 5.1.: Reconstruction phase floor plan. White furniture physically exists in the room, while orange furniture is to be placed in the task using *HomePlanAR*.

Free Phase

Finally, in the free phase participants were given a catalog containing furniture objects of a variety of sizes and instructed to freely place them as they saw fit. They were asked to place every item available in the catalog (see table 5.3) and use them to create a conference room with a small lounge area. This process was chosen to have a creative task appropriate for the lab room, which also supported a wider array of shapes. The conference table was a large rectangle shape, the chairs medium-sized square shapes, and the cupboard narrow rectangles, while the pictures were small wall-mounted objects.

Furniture Item	Quantity
Conference Table	1
Armchair	2
Table	1
Picture	4
Cupboard	2

Table 5.3.: Free phase catalog. Participants had to freely arrange all of these items to complete the task.

5.2.2. Particpants

Eight participants were recruited from the student bodies of the University of Konstanz and the HTWG Konstanz, advertising to the HTWG's faculty of architecture directly to ensure the participation of experienced space planners. Overall, two students of architecture were recruited, as well as one professional architect who had recently graduated. The other five participants were students from the university's faculties of historical studies ($n = 3$), computer science ($n = 1$), and sociology ($n = 1$). All student participants were enrolled in master's programs.

Five participants identified as female, and the other three identified as male. Ages ranged from 22 to 27, with a mean age of 25.125 ($sd = 1.96$). All participants were native German speakers and the evaluation was conducted in German. Participants were compensated for their time with 10 €.

To provide further context, participants were also asked about their level of familiarity on a scale of one to five with several technologies. Seven participants indicated a high level of familiarity with presentation software, selecting four ($n = 6$) and five ($n = 1$). One participant selected three, indicating at least a basic level of familiarity. Familiarity with 3D space planning software was divided between architects selecting five and laymen selecting one. All participants indicated a high level of familiarity with the use of smartphones selecting four ($n = 3$) and five ($n = 5$). Tablet use was more mixed, with a spread of answers including two ($n = 2$), three ($n = 2$), four ($n = 3$), and five ($n = 1$). Familiarity with AR applications was less widespread, with five participants selecting three, two selecting two, and one selecting four. Participants reported experience with other AR studies, AR games, and in one case AR as an element of an exhibition.

Finally, participants were asked about their experience level with space planning, again on a scale of one to five. Responses were mixed, with two participants indicating a high level of experience selecting four and five, three participants indicating an average level of experience selecting 3, and three participants indicating a low level of experience selecting two ($n = 2$) and one ($n = 1$).

5.2.3. Study Setting

The study was conducted in the HCI group's mixed reality lab (see figur 5.2). This is a room of 49 m^2 and square in shape. The furniture configuration during the study can be seen in figure 5.1. To stabilize AR tracking, pictures were placed along the walls of the room. During the study, the researcher sat at the desk on the left, where the participant could also sit down when being instructed, filling out questionnaires, or being interviewed. The entire room was scanned as a Vuforia area target using the Vuforia Area Target Creator app on a 2021 iPad Pro. The same iPad was also used by participants in the study.

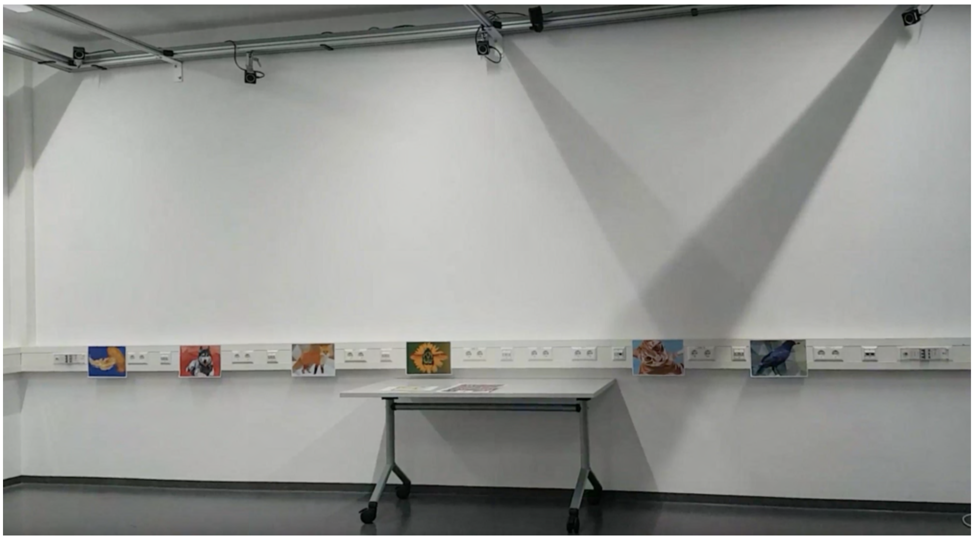

Figure 5.2.: The mixed reality lab, seen from the researcher's desk. Pictures were set up to stabilize tracking.

5.2.4. Procedure

Participants were welcomed in the mixed reality lab by the study conductor. After being informed about the purpose of the study and their rights as participants through a welcome letter and informed consent form which they signed, participants were asked to fill out a demographic questionnaire on the iPad. Then, the study conductor gave a PowerPoint presentation on all the functions of *HomePlanAR*, as well as instructions on how to perform the think-aloud technique. Participants were then handed the iPad and, guided by the study prototype, worked on all three tasks in order. Afterward, participants were asked to fill out a paper version of the system usability scale. Finally, the interview was conducted, after which participants received compensation. The entire process took approximately one hour, half of which was spent in the interviews.

5.3. Data Collection and Analysis

While performing the tasks, participants were instructed to use the think-aloud technique. Audio, the tablet's screen, and a view of the room were recorded, using the iPad's screen recorder and a tripod-mounted smartphone. During the study, in-situ notes were taken. After all three tasks were completed, participants filled out the standardized system usability scale [39]. This tool was chosen because SUS scores can be used to estimate the overall usability of a product [40], without putting it into a direct comparison. The questionnaire is available in the German language [41]. Finally, a semi-structured interview of roughly 30 minutes was conducted. In the interviews, participants were asked to rate how much the techniques helped them accomplish their goals in each task on a scale of one to ten. The contents of these interviews were evaluated in a thematic analysis.

5.3.1. Thematic Analysis

Thematic analysis is a method of qualitative data analysis originating in the field of psychology, first codified by Braun and Clarke in 2006 [42]. This method has since been applied to other fields, including human-computer interaction, for example by Hubenschmid et al. [43] Braun and Clarke emphasize the importance of making deliberate choices in the process of planning a thematic analysis and present several areas in which these choices have to be made.

The first choice is between an inductive and a theoretical approach. An inductive approach is described as a bottom-up, data-driven way to identify themes with a reduced emphasis on prior assumptions, while the theoretical approach aims to answer specific research questions. In this method, previous research may have provided some themes already, which the researcher specifically looks for in their data to derive a further understanding of how they can be expressed [42]. In this analysis, an inductive approach was chosen due to the low amount of prior research into the use of dynamic smart guides or the grid technique in AR.

Another distinction that Braun and Clarke recommend making is the level at which themes are identified. They differentiate between semantic and latent themes. Semantic themes are derived from elements directly present in the data, while latent themes are derived from interpretations of the elements present in the data to identify underlying concepts [42]. In this usability evaluation, the majority of qualitative data is sourced from the interviews conducted. Themes therefore overwhelmingly fall into the category of semantic themes, as the matter being discussed — the participant's user experience — was the direct subject of the interviews.

The final categorization Braun and Clarke present is between essentialist/realist and constructionist thematic analysis. As constructionist analysis is geared toward examining the effect of social and cultural context on experiences [42], the realist perspective is more relevant to usability evaluation. The focus on deriving themes directly from individual experiences matches the paradigm of user-centered design better.

Braun and Clarke also provide a step-by-step procedure for thematic analysis. The first step is familiarisation with the available data. As Braun and Clarke recommend, the interview data was manually transcribed into a 52-page document and then re-read several times over. In the next step, interview data is coded to start revealing patterns. In this analysis, 41 codes were defined and documented with their number of occurrences and in which interviews the codes occurred (see appendix A). The final stages are searching for, reviewing, and defining themes and producing a report presenting the themes. This process was started by creating sticky notes for each of the codes with their number of occurrences on a digital whiteboard and creating clusters forming candidate themes (see figure 5.3). The themes were then further refined through combination and more accurate naming where necessary, and given a more in-depth analysis.

Figure 5.3.: Work-in-progress candidate theme clusters on a digital whiteboard. Blue sticky notes are interview codes. Orange sticky notes are potential themes in the process of being refined.

5.4. Results

The data collected in the usability evaluation was of qualitative and quantitative nature. Both will be presented here, with a statistical description of the quantitative data and the results from the thematic analysis.

5.4.1. Quantitative Data

Quantitative data was analyzed using the statistics program R. It includes the results of the SUS questionnaire, as well as the results of interview questions where participants were asked to give numerical ratings for the usefulness of the techniques in each of the tasks.

SUS Results

The mean system usability score across all participants was 76.25 with a standard deviation of 9.91 (see figure 5.4). According to Bangor et al. [40], this indicates above-average usability. Bangor et al. provide 70 as the baseline for an acceptable rating, while "high 70s to upper 80s" indicate a more positive result. It is important to consider that this is a score for the entire prototype application and cannot directly be extrapolated to either of the alignment assistance techniques.

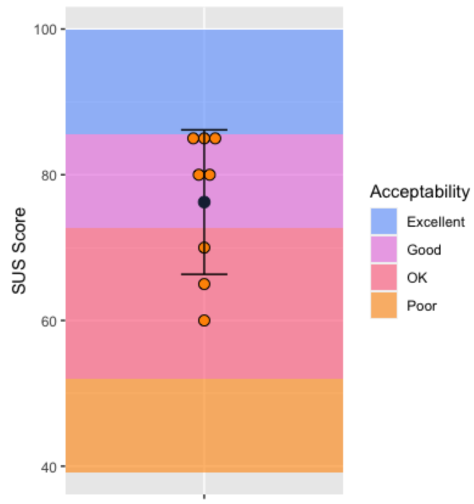

Figure 5.4.: SUS questionnaire results: Mean = 76.25 (dark blue), sd = 9.91, individual participant responses in orange, acceptability categories as described by Bangor et al. [40].

Interview Ratings

The responses to the numerical rating questions are summarized here. To give a general overview on how the techniques compared, the first visualization, Figure 5.5, displays a summarized comparison of the ratings for all tasks between the grid system [mean = 6.7, sd = 2.39] and smart dynamic guides [mean = 5.5, sd = 2.98].

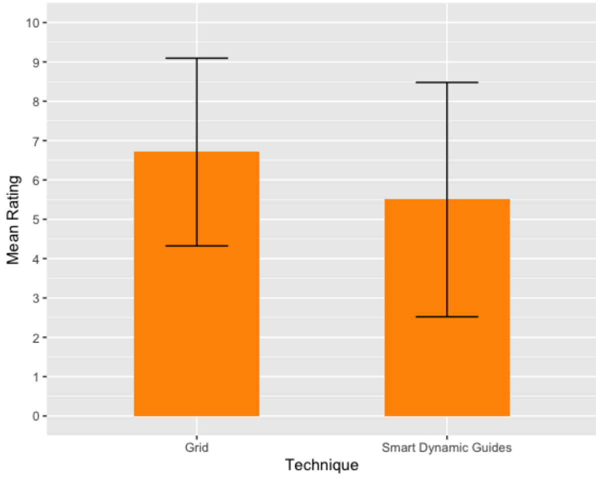

Figure 5.5.: Comparison of mean ratings per technique across all tasks, error bars display standard deviation.

In this comparison, the grid system has been rated more favorably by 1.2 points on average. Both ratings are characterized by high variability expressed in the standard deviation.

To better understand how these ratings are composed, they are also presented per task. Using dot plots that show each individual participant response, the entirety of the data can be seen here. Looking at each task individually can inform the assessment of the strengths and weaknesses of either technique.

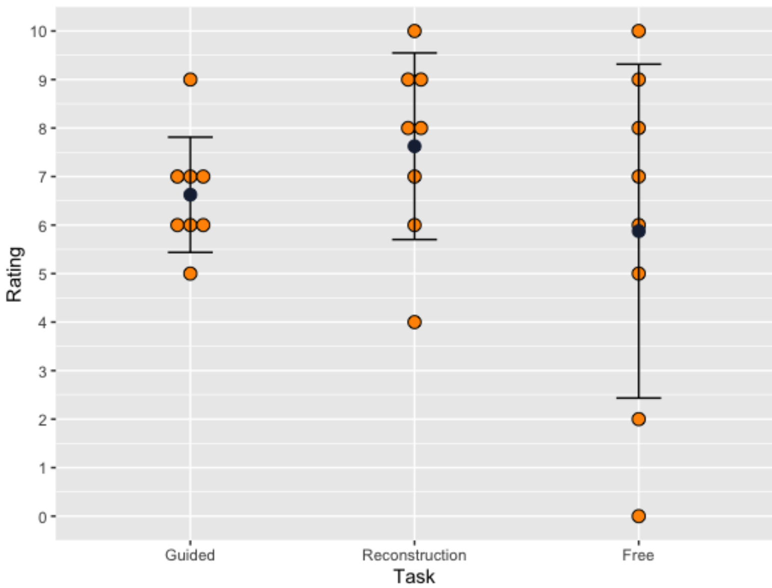

Figure 5.6.: Interview rating of the grid technique per task, mean in dark blue, individual participant responses in orange, error bars display standard deviation.

For the grid technique, this is displayed in figure 5.6. In the guided task, participants gave a mean rating of 6.63 $[sd = 1.19]$, in the reconstruction task 7.63 $[sd = 1.92]$, and in the free task 5.88 $[sd = 3.44]$. The usefulness in the reconstruction task is rated highest here, one point higher than in the guided task and 1.75

points higher than in the free task, which was rated the lowest. The free task is characterized by the highest variability by far having a standard deviation that is 1.52 points greater than in the reconstruction task and 2.25 points greater than in the guided task.

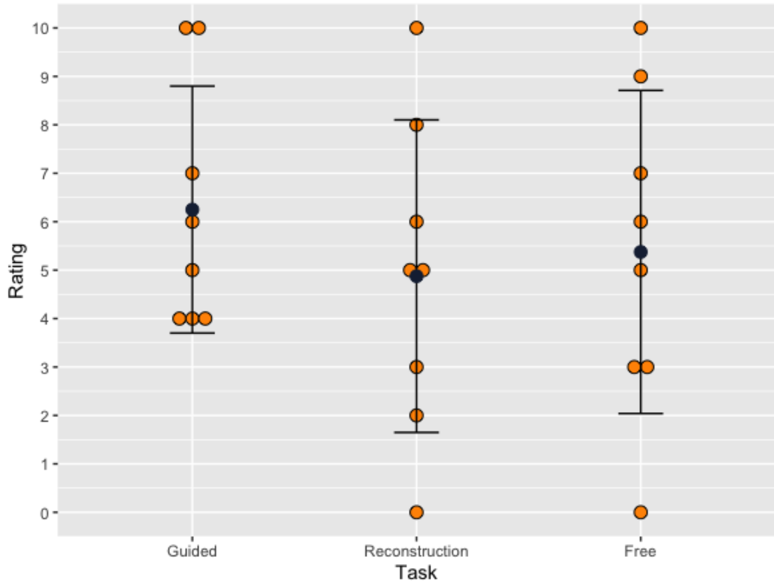

Figure 5.7.: Interview rating of the smart dynamic guide technique per task, mean in dark blue, individual participant responses in orange, error bars display standard deviation.

The smart dynamic guides (see figure 5.7) were rated 6.25 [$sd = 2.55$] for their usefulness in the guided task, 4.88 [$sd = 3.23$] in the reconstruction task, and 5.38 [$sd = 3.34$] in the free task. The reconstruction task is rated lowest here at 0.5 points fewer than the free task and 1.37 points fewer than the guided task, which was the most highly rated. The variability, with standard deviations ranging from 2.55 to 3.34 points, was overall high. The task with the greatest variability was the free task.

Between the techniques, the greatest difference in rating can be observed in the reconstruction task with 2.75 points, which is more than twice as high as the difference in overall means of 1.2. In both other tasks, the grid technique was rated higher by smaller margins, 0.38 and 0.5 for the guided and free tasks respectively. For both techniques, the highest variability in rating could be observed in the free task.

Due to the low number of participants, this data is not suitable for statistical significance testing. As the questions were concerning the usefulness of the technique in the respective tasks, the data can't directly be used as a rating of the technique itself.

5.4.2. Thematic Analysis

The following section presents the findings of the thematic analysis. It details each of the eleven themes identified in the interview and observation data. These themes have been refined from the original candidate themes through revision and consolidation (see figure 5.8). Direct quotations from participants have been translated from German for presentation purposes here. The unedited quotes can be found in order of appearance in appendix B. Participants P1 through P3 had a background in architecture, either being enrolled for or having a completed master's degree. The remaining participants P4 through P8 did not have professional experience in architecture.

Figure 5.8.: Final state of the digital whiteboard used to determine themes. Blue notes are interview codes. Green notes contain direct quotes concerning the theme. Orange notes are themes, where previous versions are stacked below the final revision and lighter orange themes are previously independent themes that have been consolidated.

Theme #1: AR in *HomePlanAR* is a fun, "hands-on" way to support space planning.

A consistently reoccurring theme across all participants was a generally positive attitude toward the use of AR in space planning. Participants praised the application for being enjoyable to use (P1, P3, P5, P7, P8) and intuitive (P1, P2, P4, P5, P7, P8), stating that "it's a lot of fun," [P1] "the idea is cool and works well for placing furniture," [P7] and that they "didn't need the explanation and would have been able to use the basic features without it." [P4] This is also reflected in the positive average SUS score.

Participants especially praised the way that "it was very intuitive to see the items that you placed directly in the room" [P2]. Placing items "helps with spatial imagination." [P2] This also plays into the perception that the application offered a fast way to try out various items without any commitment. Participants identified "the variety, to furnish everything and put furniture directly into the room without having to measure anything" [P5] as a strength of the application (P1, P3, P5, P6, P7, P8). This does indicate a tendency toward a more imprecise mode of testing rather than rigorous planning, as P2 stated.

Theme #2: Smart dynamic guides preferably for measuring over alignments.

All participants except for P6 explicitly expressed satisfaction with using the smart dynamic guides to measure distances. The ability to "estimate real distances and get exact reference points" [P2] was seen as an overall strong point of the application. P8 remarked how it enabled her to "plan out, in at which distances you want to arrange things, and then re-create that in reality."

However, the participants also pointed out issues with the implicit targeting inherent to smart dynamic guides. All of them except P3 mentioned this in some capacity. The main problem they encountered was the smart dynamic guides latching on to a constraint of an object unrelated to the task they were trying to accomplish (P1, P2, P4, P5, P6, P7, P8). "Sometimes they worked well, other times they displayed the wrong thing. There was a bit of a surprise effect," P4 stated. She elaborated further that this was an issue already familiar to her from PowerPoint: "I have to say that they are a little random in PowerPoint, too, sometimes. I think I may generally have an issue with these things." This parallel was also noted by P6 and P7. This led participants to commonly suggest forms of explicitly selecting which constraints the smart guides should be using for alignment and measurement purposes (P4, P5, P6, P7): "Maybe it would make sense to be able to designate objects to say you don't want to snap to them at the moment." [P6] "It would be cool if you could determine two points where the distance is shown." [P5]

Participants P1 and P6 even went so far as to suggest a pure measuring tool independent of the smart dynamic guide system. Overall participants preferred the measuring feature, which they remarked worked well, over the alignment feature that they encountered issues with. At the same time, the visualization used was described as familiar and useful (P1, P2, P3, P4, P5, P6, P7, P8) and the guides behaved as expected (P1, P2, P3, P4, P6, P7, P8), but this likely played a role in those issues.

Theme #3: Smart dynamic guides for aligning pictures.

There was one special case where participants did use the smart dynamic guides for alignment a lot more frequently than in general use, which was arranging pictures. This was specifically mentioned by P1, P2, P5, P6, and P8, but could also be observed with P3 and P4. "Especially when placing pictures it was really cool," P1 noted when asked about how the dynamic smart guides fulfilled her expectations. P6 also identified arranging pictures when asked about the strengths of smart dynamic guides.

This could have interesting implications when considered with another common sentiment, which was experiencing issues with depth perception (P1, P2, P3, P7, P8). Usually, this was expressed in difficulties with estimating sizes. Explaining problems she experienced with understanding where smart dynamic guides were attached to the real furniture items, P2 noted: "Maybe this was because I could not accurately estimate, at which depth the smart guide is, whether it's closer to me or further away. That was difficult, too." This can be explained by a tablet's lack of stereoscopic view. However, P7 offers an additional factor in this issue, while explaining their process of placing furniture in the reconstruction task: "When it was multiple pieces of furniture, I tried picking the one farthest away from me, and then the next-farthest, because otherwise I would have had to place items behind." Obstruction can make the perception of smart dynamic guides harder, too. P3 wished that she could "set the object to being transparent, so I can see where it is behind it." Alternatively a "top view floor plan" would also have been seen as helpful by her.

When manipulating pictures on the walls, participants did not experience the same issues, as here they could always see all sides of the object they were manipulating, just as they were used to from presentation software.

Theme #4: Grid for aligning rotations with the walls of the room.

The most common use for the grid feature was rotating objects to be aligned with the walls of the room or at a 45° angle to them (P1, P2, P5, P6, P7, P8). Participants tended to try to "align items in parallel and enabled the grid feature to see them having the same orientation." [P1] Participants referred to this 17 times in total during the interviews, revealing it as an integral part of their process of solving the study tasks. For some of them, this was even the main purpose of the grid: "I used the grid to set objects parallel to the wall. I also used the grid to rotate objects, for example, to put the chairs in the seating area into a 45° angle, that just looks cleaner." [P6]

This strong impulse to align furniture with the walls led to participants rarely using the re-orientation feature of the grid. Only P8 could be observed doing this in the re-construction task when aligning the tables with a 22.5° angle to the wall and their respective chairs, a task where the other participants either used smart dynamic guides or just freely estimated the rotations. P8 however remarked: "I liked the ability to rotate the entire grid a lot. I only used it once, but in that situation, it was very helpful."

Overall, participants found the rotation feature of the grid to be very helpful but mostly stuck to the default orientation along the walls, which provided them with the ability to accomplish the majority of rotation tasks. This contributed to an overall good impression of the grid system (P1, P2, P4, P5, P7, P8).

Theme #5: Either grid or smart dynamic guides for structuring the room.

Participants fell into one of two groups when it came to creating structure in their rooms. The larger group (P1, P2, P4, P5, P7, P8) worked in the grid mode most of the time and only switched it off to deliberately go off the grid or use smart dynamic guides to accurately measure a distance. The smaller group (P3, P6) used smart dynamic guides most of the time and only switched them off when they encountered issues with getting the guide to catch the intended constraint or wanted to use the grid to rotate items.

Interestingly enough this distinction carried into the subset of professional architects, where P1 and P2 strongly favored the grid, describing how it gave them "a basis, on top of which you can build the room. Especially if you don't have a strong idea what the room is going to look like, a grid like this is always helpful." [P1]. P3 on the other hand expressed a general dislike of grid systems explaining that she had the impression that the grid was "not needed" and relating to her day-to-day experience with planning software: "This grid is also available in ArchiCAD, I usually disable it." This is reminiscent of P4, P6, and P7's experiences with smart dynamic guides in Powerpoint: "Yes, they are similar to PowerPoint. Sometimes they frustrate me there, too." [P7]

Theme #6: The visualization of the grid was strong but should have been placed directly on the ground.

The most common critique participants offered for the grid feature was that the grid did not appear directly on the floor, making it harder to understand distances and alignments (P1, P2, P3, P5, P7). Otherwise, participants were positive about the visualization, praising how the coloration helped it "blend into the background, " being "visible but not dominant." [P2]

A simple solution to this issue would be to simply attach the grid directly to the ground. P2 however suggested there could be more potential uses for the positioning of the grid: "It would be cool if you could tell the grid, on which level it should be. If you could for example say 'I want the desk's top to be the basis for the grid', or the floor, or the wall. Having the ability to pick a reference point and expand the grid from there would be a useful feature."

Theme #7: Both alignment assistance tools serve complementing purposes when available separately, but there is potential in combining them.

Participants enjoyed being able to "pick what works best" [P1] for them and each respective task. As already touched upon in theme #5, five participants preferred the grid overall (P1, P2, P4, P5, P7, P8), while two participants preferred the dynamic smart guides (P3, P6). However, each participant also saw applications for the other technique. Five participants would see an advantage in combining the two tools (P2, P3, P4, P7, P8), while two did not see an advantage in this (P1, P5).

Simply enabling both techniques simultaneously would lead to conflicts between alignments with smart dynamic guides and grid position. In this scenario, participants tended to prefer giving the grid priority: "Preferably the grid, because that is what the other pieces of furniture were also aligned to in my approach." [P2]

Theme #8: Selection/de-selection and the start/end of manipulation of an object's position should be separate to safeguard against unintentional manipulations.

Several participants described problems with unintentional manipulations after selecting an object when they only wanted to rotate it or check distances using the smart dynamic guides (P1, P3, P5, P6, P7). This led to several suggestions on how to enable more deliberate manipulations. The most common of which was the idea of a separate positioning mode that would have to be enabled by symbolically picking up the item and disabled by setting it down: "I think it would be satisfying when you move an armchair somewhere, click a checkmark, and then have it really be put there," P1 explained, and even elaborated her idea with a sketch (see figure 5.9). This idea was in part inspired by the video game series "The Sims", in which the player can build and furnish houses. In her sketch, she also proposed a measuring-only function that would display smart guides without the prerequisite of alignment, which P6 also envisioned.

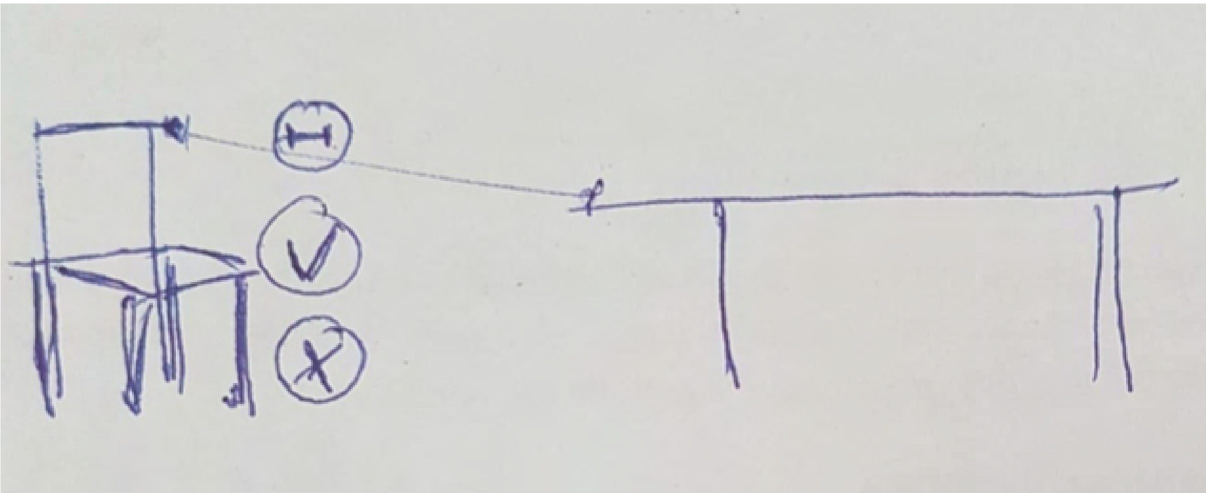

Figure 5.9.: P1's confirmation UI sketch with world space buttons to put a chair into place with the checkmark or delete it with the X. This also includes the idea of a pure measuring function on the third button [P1].

Theme #9: Grid scaling was rarely used, but important to those who did.

Only two participants could be observed using the scaling feature of the grid more than once (P7, P8), but they used the scaling feature throughout the entire study. P7 explained that this helped him "estimate distances well".

Participants who did not scale the grid either used it less overall because they preferred the smart dynamic guides (P3, P6), or found the default value sufficient for their workflow: "I didn't do that [manipulate the grid], I liked the 10cm grid." [P4]

Theme #10: The form of AR in *HomePlanAR* was not seen as applicable to a professional planning tool, but for presentation.

All three participants with a background in architecture noted that an application like *HomePlanAR* would not have a place in their professional workflow. The problem that using AR for space planning aims to solve — having to imagine the impression of the finished room from traditional planning tools like floor plans — is something that architects are specifically trained to be good at (P2, P3): "Through the study of architecture, you learn how to imagine this, therefore the help with seeing how items look in the room is maybe not always necessary." [P2] P3 also did not see a need to integrate AR into her planning process: "I wouldn't want to really plan with software like this — we have our CAD-drawing programs for planning." P1 elaborated on this issue, explaining that the planning process for architects rarely involves being at the actual location, as commuting between them would not be an effective use of time.

Where P2 and P3 did however see a lot of potential for AR was in the ability to use it for presentation purposes. The scenario both proposed was the ability to bring a tablet on-site with their client and "hand it to them, so they can get an impression [of what it looks like]." [P2] P3 also identified this as a prevalent issue, where architects "know what we envision, but people — our clients, or others that we need to convince — can't envision it quite as well, because they aren't used doing that every day."

Theme #11: Distances are difficult to estimate using only the grid.

Two participants (P4, P5) reported having issues estimating distances using the grid system. "I found making measurements difficult. The grid helped, but I couldn't really see it correctly," P4 explained. This would not be prevalent enough in the participant responses to form a theme necessarily. However, all participants except for P6 mentioned preferring the smart dynamic guides for measuring. This could indirectly indicate at least some of them also experiencing difficulty using the grid system for measuring.

5.5. Discussion

This section uses the study results to find insights concerning the research questions defined in 5.1. It also functions as a summary from the perspective of the agile UX lifecycle [33].

5.5.1. Smart Dynamic Guides and the Grid System supporting Space Planning (RQ1)

Concerning **RQ1**, the question of how smart dynamic guides and the grid can support space planning in AR, several factors speak in favor of both smart dynamic guides and the grid system showing potential for AR space planning. AR space planning, as evidenced in many commercial demos and applications and here in **theme #1**, is a prime use case for AR. The overall good SUS results presented in 5.4.1 support that *HomePlanAR* represented the techniques well and give an indication that they were useful to the participants. The results of asking participants to rate the technique's usefulness are not quite as clear. While on average being on the upper half of the scale, only the grid system is decidedly so at a 6.7 out of 10, while the smart dynamic guides at 5.5 out of 10 only barely pass the halfway point. **Theme #5** and the individual participant ratings offer possible explanations for this: Participants formed strong preferences for which tools they used to perform the majority of the work on the tasks. As fewer participants ended up preferring the smart dynamic guides, their ratings naturally ended up lower. Those who did prefer the smart dynamic guides did however rate them highly. Furthermore, both groups also saw practical applications for the respective other technique even when they didn't end up using it as often, as summarized in **theme #7**.

Overall the study demonstrated the potential both of smart dynamic guides and the grid system to support AR space planning. As the summative evaluation step in an agile UX design cycle [33], it had a positive outcome, but also exposed many areas where improvements can be made. These in turn contribute insights to the remaining research questions.

5.5.2. Usage Patterns for Smart Dynamic Guides and the Grid System (RQ2)

Both techniques had applications that participants almost universally pointed out as especially helpful to them. For smart dynamic guides, this was the ability to retrieve accurate measurements between objects, which was described in **theme #2**. For the grid system, this was the ability to rotate the furniture in 45° steps and align it with the walls of the room described in **theme #4**. Making alignments, on the other hand, saw a greater polarisation among participants, who either strongly preferred the grid system or the smart dynamic guides as mentioned earlier, with the former group being larger.

Several factors could play into this. Some participants mentioned a pre-existing preference or dislike for one of the techniques, stemming from their experiences with other software. A dislike of the way smart dynamic guides affected alignments often was connected to experiencing similar issues in Microsoft PowerPoint and *HomePlanAR*. Likewise, P3's report of usually disabling the grid ArchiCAD indicated similar personal preferences. Alternatively, the largest difference in mean rating was in the reconstruction task, where the grid system was rated 7.36 and the smart dynamic guides 4.88 out of ten. For the grid system, this was the highest rating out of all three tasks, while for the smart dynamic guides, it was the lowest. This could indicate that the grid system was suited better to re-create a large-scale complex layout with many objects in the room, which in turn may have biased the participants to be more positive towards the grid system in general. In the free task, the degree to and ways in which participants used the techniques varied greatly, which is also reflected in the greatest standard deviation in rating for either technique being found here, so it is unclear whether this effect manifested.

Another explanation for the prevalent preference for the grid system when making alignments could also be that it served this purpose overall better. Participants who preferred it over smart dynamic guides commonly reported having issues getting the smart dynamic guides to snap into the intended alignment, an issue that may be inherent to the technique itself, as it was also explained to be occurring in Microsoft PowerPoint. This sentiment was even carried by P6, who was one of the two participants favoring the smart dynamic guides. The issue may even be more severe in an AR setting because of obstruction effects that P3 brought up, and which may be indicated further by **theme #3**.

Theme #3 describes how participants disproportionally used smart dynamic guides to align pictures over other objects. The reason for this could be that unlike on the ground level, on walls participants could see all sides of the object relevant for making alignments at all times. This made using the smart dynamic guides on walls more similar to using them in a traditional 2D layout context. However, this observation could also be explained by the walls generally being populated with objects more sparsely, which reduced the risk of unintentional alignments being snapped into.

Despite participants regularly using the grid system to align objects, they rarely used the options they had to manipulate the size and orientation of the grid. As a reason for this, many participants expressed satisfaction with the default values, especially concerning the rotation. It is possible participants would have been incentivized to adjust the grid size more often if it had been easier to read distances directly from the grid, which is an issue documented in **theme #11**. The manipulation of the grid's rotation on the other hand could have been more relevant in a non-rectangular space.

5.5.3. Design Improvements (RQ3)

The study revealed multiple improvements that could be made to the prototype. They will be presented aligned with the areas of the application they are concerned with.

Smart Dynamic Guides

Two major issues were identified with the usability of smart dynamic guides: Problems with unintended snapping and problems with obstruction.

This thesis identifies two approaches to dealing with the issue of unintended snapping, which are derived from the main scenarios where it occurs. In the first, most common, scenario, the user intends to measure the distance between two objects but does not want to manipulate the position or rotation at all. A straightforward solution to this is the introduction of a pure measuring mode. This idea was often proposed in the interviews, too. It would be a third mode that users can toggle in addition to smart dynamic guides and the grid system. In this mode, selected objects continually poll along their sides for other objects, regardless of given alignments. The same distance marker used in the regular smart dynamic guide mode would then be placed along the shortest distance between the selected object and any other objects found (see figure 5.10).

The other approach, which was proposed by P2 and P6, addresses the issue where users try to align two objects and have additional objects interfere. This problem can be avoided by giving users the ability to choose objects to be ignored by the smart dynamic guides. The interaction to achieve this is a bit more complex. A way to enable it is the introduction of another sub-mode when smart dynamic guides are activated, in which regular selection and de-selection of objects are suspended. Instead, whenever the user touches an object — including real objects — they toggle whether the object's constraints are considered for the detection of smart dynamic guide alignments. By default, all objects would be enabled. In the target-modification sub-mode, whether an object is smart dynamic guide-enabled could be denoted by adding a color shader to it. Alternatively, objects could be disabled by default, with users always having to explicitly pick which objects they want to align to. This may be beneficial in more target-dense environments.

Participants reported issues with obstruction making it difficult to perceive constraints that affected the objects they manipulated from directly behind the objects. This led to snapping behavior occurring unpredictably. By making the selected object transparent, users are still able to perceive smart dynamic guides that appear behind

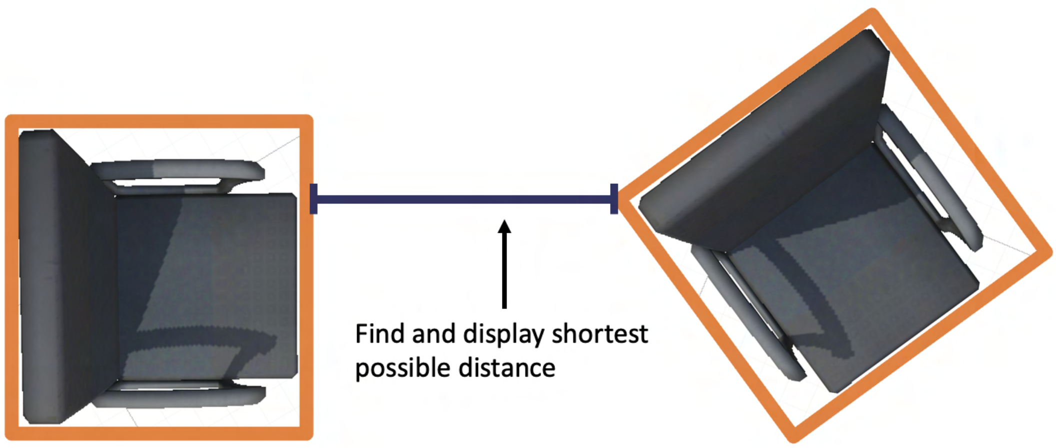

Figure 5.10.: Visualization of how a measuring tool could find and display distances between non-aligned objects.

the object from their perspective. This yields the additional benefit that object selection is denoted more clearly. A mockup of this, created in the *HomePlanAR* prototype, can be seen in figure 5.11.

Figure 5.11.: Making the active object transparent in *HomePlanAR* allows users to see smart dynamic guides connected to constraints that are directly behind the object.

Grid System

The issues identified with the grid system were not as severe as with the smart dynamic guides. Regardless, some improvements could be made and one problem with the visualization was noted frequently (see **theme #6**).

That problem is the positioning of the grid visualization. Participants remarked that the grid should have been displayed directly on the ground. This simple change could resolve most issues concerning this. However, P2 proposed an idea that could increase the utility of the grid system. She envisioned the ability to freely align the grid to different constraints, providing the example of a tabletop. One way to enable this would be to provide users with an additional slider that manipulates the height at which the grid is displayed. The zero position of the slider would place the grid directly on the ground. As the grid's height is manipulated, the slider would snap into positions where the grid is aligned with a constraint in the room.

Figure 5.12.: Alternating color grid lines in *HomePlanAR*. Orange lines are added between each of the blue lines.

Another smaller issue participants encountered was difficulty estimating distances using only the grid (see **theme #11**). This could partly be addressed with the pure measuring function described in 5.5.3. However, P5 brought up an alteration that could further support this. By alternating two colors between the grid lines, it could be easier to read them. A mockup of this, created by modifying the *HomePlanAR* prototype, can be seen in figure 5.12.

P3 also brought up some changes to the behavior of objects on the grid, where rather than having the center of the active object snap to the intersections of grid lines, she would have preferred the constraints of the active object to snap to the grid lines. As she was the only participant noting this, it is difficult to estimate how much of an improvement this would be, if any.

AR Medium

Many of the issues encountered with the application may have been exacerbated by issues with depth perception (P1, P2, P3, P7, P8). This is a limitation inherent to using a tablet as AR device, which may be alleviated by the use of a stereoscopic device like the Microsoft Hololens or Varjo XR3. Naturally, this would require a major re-design of the user interface to accommodate the new medium. A starting point could be the increased use of world space buttons P1 suggested in the sketch she provided (see figure 5.9).

The choice to change the AR medium does not only come with upsides, though. Tablet- and smartphone-AR has the advantage of being widely available today, while AR head-mounted devices (HMDs) still aren't present on the consumer market. As AR space planning is more suited to consumer applications for reasons explored in

theme #10, the proliferation of AR devices is an important ecological factor to consider. HMD AR also requires a careful re-examination of the interaction techniques used to manipulate objects.

5.5.4. Implications for 3D Manipulation in AR

While space planning is a special case of 3D manipulation with several limitations, some of the insights gained in the evaluation of *HomePlanAR* have implications that are interesting to the field in general.

Smart dynamic guides are a technique that is not just applicable to space planning. With their constraint-snapping visualizations, Nuernberger et al. [27] explored a similar concept. However, they did not uncover the obstruction issues participants encountered in this study. This may have been caused by their setting featuring the participant in a static position, which caused fewer and less drastic perspective shifts. Likewise, this issue may not be as relevant in 3D editors that offer smart dynamic guides like ArchiCAD. Changing the perspective in those editors is a lot quicker and low-cost than in AR, where the user has to physically move to change their perspective.

The issue of unintended snapping in a target-dense environment is also just as relevant to general 3D manipulation in AR as it is to space planning. Applications using smart dynamic guides need to consider the expected density of targets and if necessary provide methods to restrict the snapping behavior. This is again a problem that did not emerge in Nuernberger et al.'s controlled experimental setting [27].

In principle, a grid system is also viable for general 3D layout creation in AR, as the concept is also used in non-AR applications. It is not clear, whether the visualization presented in *HomePlanAR* is completely transferrable, though. The idea of displaying a plane with the grid on it, which can be adjusted in height and snapped to object constraints, seems to hold potential for this, though.

5.5.5. Limitations

As the subject of this thesis is a usability evaluation, the number of participants was low, which limits the generalizability of these results. The evaluation also did not focus on performance metrics in favor of gathering more detailed insights into the participant's interaction patterns. This decision was made as neither of the techniques was well established in an AR context and due to the low number of participants, this data would not have been able to inform conclusive statements.

Another limitation is that in the evaluation, it was difficult to differentiate between the impacts the two techniques had since participants were free to select when and how they used which of the tools. This tradeoff was taken to gain a better understanding of how the techniques would be used in a less artificial setting.

Finally, the problem domain of space planning is a highly specialized case of 3D manipulation and layout creation. This had the benefit of the tasks being easily understood and motivating for the participants but makes it difficult to directly translate any findings presented here to the generically applicable domain without further examination.

5.5.6. Future Work

The results of this evaluation can provide a basis for future works in several ways. The area of 3D layout creation using AR has not been explored deeply, yet. Both techniques presented represent opportunities to improve the understanding of this area. The next logical steps following this research are high-rigor tests of the implications derived from the results of this study.

Implementing smart dynamic guides for an experimental setting similar to that used by Nuernberger et al. [27] could be a good way to test the impact occlusion and transparency have on the effectiveness of the technique. The setting would need to be less static and require the participants to use multiple perspectives. This could be accomplished by having them work around a free-standing table. In a study like this, participants would solve consecutive positioning and scaling tasks. In each task, they would place a set of items, docking them to ghost targets to form an arrangement. This is a task commonly used to evaluate 3D manipulation techniques [44, 45]. The environment around them would have additional objects, possibly physical, placed in it, providing constraints that could be snapped to. The independent variables in an experiment like this could be a condition with no alignment assistance, a condition with smart dynamic guides and a solid selected object, and a condition with smart dynamic guides and a transparent selected object. The experiment could observe the effects on task completion time, precision, and cognitive load. This could confirm some of the findings concerning the use of smart dynamic guides in AR layout creation.

Another topic for future research is the selection and de-selection of constraints that affect smart dynamic guides. As proposed in 5.5.3, this can be accomplished by either allowing users to de-select constraints from the smart dynamic guide system — *explicit constraint de-selection* — or by requiring them to explicitly select them — *explicit constraint selection*. This could be compared in a similar experimental setting as described earlier in this section, with participants performing a docking task with a set of items to create an arrangement. An independent variable this experiment could examine in addition to the two methods of *explicit constraint de-selection* and *explicit constraint selection* is the density of potentially interfering constraints in the environment. This could be used to test whether, for example, *explicit constraint selection* has an advantage in environments with a high target density.

The grid system in *HomePlanAR* seemed to be a more mature technique overall, prompting perhaps fewer obvious areas of research. Some future work can be envisioned concerning different visualizations of the grid. Alternatively, the grid could be used in comparisons with other techniques.

An interesting research topic would be the comparison of different visualizations for the grid in generic 3D AR manipulation, utilizing the docking task described earlier. The visualization used in *HomePlanAR*, adjusted as described in 5.5.3 to show the grid lines in alternating color, could be compared to a full cubic 3D grid to test whether the more detailed nature of a full grid provides an advantage or creates issues with optical clutter.

Finally, the refined version of both smart dynamic guides and the scaleable grid could be evaluated in a comparative study, using either a space planning or a generic 3D layout task. The insights gained in the study presented here inform improvements that can be made to the design of either technique. A follow-up study can be used to evaluate those improvements and assess their effect on how users utilize the techniques.

In all of these scenarios, the AR medium is a variable that could also yield interesting insights into the impact of stereoscopic vision. One research question concerning this could be whether alignment assistance techniques provide a greater benefit on flat-screen AR versus HMD AR, compensating for the lack of depth perception.

6. Conclusion

Existing solutions for AR space planning prioritize the presentation of 3D content over the support of layout creation in a physical environment. This thesis presented two methods for supporting space planning in AR better, established in other domains of layout creation. As research specifically into the creation of layouts using AR is sparse, it drew heavily from non-AR industry tools. For the first method, smart dynamic guides, known from presentation software, were introduced to AR. They enable users to intuitively snap objects into alignments with each other and to quickly measure distances between them. The second method, a scaleable grid, enables users to arrange objects using an overlaying system and to quickly rotate them into commonly used orientations. Both of these methods are well-established in non-AR applications. Related research has so far primarily provided the technological foundations for understanding physical environments concerning alignments. Only one research paper offered interaction techniques approaching smart dynamic guides, taking the perspective of 3D object manipulation instead of 3D layout creation or even space planning specifically.

As the research concerning space planning as a 3D layout task is fairly uncharted space, this thesis took a more explorative approach to the topic. Referencing the existing related work and usage research conducted for the project for this thesis, the techniques that were identified in non-AR software related to the domain were implemented into an AR space planning application. The application enabled users to create layouts by placing various furnishing items on the floor and walls of a room. Users were free to choose smart dynamic guides or a scaleable grid to assist them with this. Smart dynamic guides automatically detected alignments, snapping objects into them and visualizing those alignments. The scaleable grid modified the movement of objects so they snapped to the intersections of grid lines. The grid could be scaled between 1cm and 100cm for the sides of the cells.

This prototype was evaluated in a usability study with eight participants to generate insights into possible design improvements and usage patterns that could inform further research. An in-depth thematic analysis was conducted to understand the large volume of qualitative data collected. Overall it appeared that the scaleable grid technique was a more mature and successful implementation than smart dynamic guides, being preferred by a majority of participants. However, participants identified scenarios where either technique was helpful to them. Participants gravitated toward using smart dynamic guides for measuring distances and using the scaleable grid to adjust rotations. For making arrangements, one group preferred the scaleable grid, while a smaller group preferred smart dynamic guides. It was also possible to derive design improvements for both techniques. Some of these improvements have the potential to apply to general 3D layout creation.

The main issue the study uncovered with smart dynamic guides was that in a target-dense environment, it became increasingly difficult to put objects into desirable alignments. Participants often struggled with objects snapping into alignments with other objects in the room that they were not trying to refer to. In the discussion of the study results, this thesis suggests enabling users to disable snapping to some objects. Alternatively, users could explicitly have to choose which objects would be enabled for smart dynamic guides. Comparing these two approaches, observing the impact of the variable of target density in the given environment, is an opportunity for future research.

Another improvement that can be made to smart dynamic guides for use in AR specifically is adding transparency to the object that is being manipulated to avoid obstruction issues. Previous research identified the need for clear visualization of the constraints affecting object snapping but did not account for the scenario, where the constraint causing a snapping behavior is directly behind the actively manipulated object.

Concerning the scaleable grid, some ideas were raised concerning the visualization of the grid. Participants indicated that the grid position needs to be meaningful, either being directly attached to the floor or planar constraints in the environment. Different forms of visualizations could be compared in future research.

By providing an explorative evaluation of some techniques for the AR space planning scenario, this thesis presented a variety of ways in which the area of space planning and 3D layout creation using AR could be advanced. The techniques presented show great potential to support the use case. Evaluating the questions raised here in a formal experimental setting could form the basis for a better understanding of how AR can best support space planning and 3D layout creation.

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A. Interview Codes

Code	Occurences	Participants	Explanation
Fun	5	P1, P3, P5, P7, P8	Expression of having had fun with the application.
Intuitive	6	P1, P2, P4, P5, P7,P8	Expression that the application was intuitive.
LearningCurve	2	P1, P2	Talking about the application having a learning curve.
MultiselectIssues	1	P1	Issues with the multiselection input.
LowCommitTesting	7	P1, P3, P5, P6, P7, P8	Praise of the ability to try out room configurations with low commitment.
DepthIssues	9	P1, P2, P3, P7, P8	Issues created by the lack of depth perception.
Confirmation	6	P1, P5, P7	Desire to have a feature that confirms the placement of furniture items and locks them in place.
Sims	3	P1, P4	References to the video game "The Sims".
ManipulationConflict	1	P1	Mentions of conflicts between translation and rotation manipulation.
Undo	2	P1, P3	Desire to have an undo/redo feature.
Feature	24	P1, P2, P3, P4, P5, P6, P7	Unique feature suggestions.
GridRotation	17	P1, P2, P5, P6, P7, P8	Mention of using the grid feature for aligning the rotation of furniture items.
SmartGuideTargeting	17	P1, P2, P4, P5, P6, P7, P8	Issues with the targeting of smart dynamic guides.
SmartGuideMeasuring	14	P1, P2, P3, P4, P5, P7, P8	Mention of using the smart dynamic guide feature for measuring distances.
PureMeasuring	2	P1, P6	Desire to be able to just measure distances.

Table A.1.: Interview codes.

Code	Occurences	Participants	Explanation
SmartGuidesReadable	8	P1, P2, P3, P4, P5, P6, P7, P8	Mention of the smart dynamic guides having good readability.
SmartGuidesExpected	9	P1, P2, P3, P4, P5, P6, P7, P8	Affirmation that the smart dynamic guides met expectations.
GridGood	13	P1, P2, P4, P5, P7,P8	Satisfaction with the grid feature.
GridToFloor	7	P1, P2, P3, P5, P7	Desire to have the grid visualized directly on the floor.
SmartGuidePictures	8	P1, P2, P5, P6, P8	Mention of the smart dynamic guide feature being especially useful for aligning pictures.
GridSpinRare	1	P1	Expression of not having used the re-orientation feature of the grid.
ToolsGoodForVariety	1	P1	Expression of both assistants being useful in their own ways.
ToolsSeparate	2	P1, P5	Preference for the assistants to be used separately.
VisualisationHelpful	2	P2	Expression that the application was useful to visualize space planning.
TabletHeavy	1	P2	Issues with ergonomics due to the tablet's weight.
NotProfessional	4	P1, P2, P3	Expression, that the application is not suitable for professional planning.
NoScaling	5	P2, P4, P6	Mention of not using the grid's scaling feature.
ImpreciseTesting	1	P2	Expression, that testing of room configurations does not always require accuracy.
ToolsCombined	6	P2, P3, P4, P7, P8	Preference for the assistants to be enabled for combined use.
GridInaccurate	3	P3, P4	Issues, where the grid was perceived as inaccurate.
CentreBad	1	P3	Frustration with the grid using the center of objects as reference.
GuidesGood	6	P3, P6	Satisfaction with the smart dynamic guide feature.
GuidesRotation	1	P3	Mention of using the smart dynamic guide feature to align rotations.
GridNotNeeded	2	P3	Expression of not needing to use the grid.

Table A.2.: Interview codes continued.

Code	Occurences	Participants	Explanation
GridMeasureDifficult	1	P4	Issues with estimating distances using the grid.
PowerPointTargeting	4	P4, P6, P7	Referring to issues with smart dynamic guide targeting in PowerPoint.
ExplicitSmartGuideTargeting	4	P4, P5, P6, P7	Desire to explicitly chose where smart dynamic guides are displayed.
GridVisualisationGood	4	P1, P2, P4, P8	Satisfaction with the visualization of the grid.
IndividualAxisManipulation	1	P5	Desire to individually manipulate individual axes.
ScalingGood	2	P7	Satisfaction with the ability to scale the grid.
GridSpin	1	P8	Reference to using the re-orientation feature of the grid.

Table A.3.: Interview codes continued.

B. Interview Extracts

Theme #1

"Das macht eigentlich echt Spaß." [P1]

"Ich fand die Idee ziemlich cool und sie funktioniert, wenn man die Möbel nimmt und platziert recht gut." [P7]

"Ich glaube auch ohne die Erklärung hätte ich so die Grundsachen auch hinbekommen." [P4]

"Es ist sehr intuitiv gewesen, dass man die Sachen, die man platzieren konnte, direkt dann auch so im Raum gesehen hat." [P2]

"Einmal dieser Freiheiten, die man hat, dieses freie Platzieren da drauf. Auch die Varianz, man kann ja alles mögliche an Möbelstücken einbauen. Eben die Möglichkeit, alles einzurichten und Möbel in den Raum zu stellen, ohne alles ausmessen zu müssen." [P5]

Theme #2

"Auf jeden Fall darin, dass man den realen Abstand damit abschätzen kann und man genauere Anhaltspunkte hat, und, dass man die Sachen auf der selben Höhe platzieren kann. Also was die Bilder anging, war das super praktisch, dass sich da dann die richtigen Höhen gefangen haben und man direkt sagen kann, wo die Bilder dann hin müssen. Das sind die beiden Hauptaspekte." [P2]

"Man kann ziemlich gut sich vorher planen, wie man in welchen Abständen etwas anordnen möchte und es dann auch genauso wieder herstellen in der Realität." [P8]

"Teilweise haben sie gut funktioniert, teilweise haben sie das Falsche angezeigt. Es war so ein bisschen ein Überraschungseffekt." [P4]

"Ich muss sagen bei Powerpoint sind die auch teilweise ein bisschen random. Ich glaube ich habe allgemein Probleme mit den Dingern." [P4]

"Ich weiß nicht, ob es Sinn machen würde, Objekte zu designieren und zu sagen ich möchte jetzt nicht zu dem Snappen in dem Moment." [P6]

"Es wäre cool, wenn man wirklich die zwei Punkte bestimmen könnte, von denen es den Abstand anzeigen soll." [P5]

Theme #3

"Vor allem wenn man Bilder aufhängt, ist das ja eigentlich echt cool." [P1]

"Es war vielleicht nicht immer ganz klar, wo der Punkt war, von dem es jetzt gefangen hat. Zum Beispiel hat es sich ja auch an den realen Objekten gefangen, da war ich mir nicht ganz sicher von wo, ob das jetzt die Tischkante oder das reale Stuhlbein war, das war mir nicht so ganz klar immer. Vielleicht auch, weil ich nicht ganz so abschätzen konnte, auf welcher Tiefe der Smart Guide gerade ist, ob der näher an mir dran ist oder weiter entfernt. Das war auch noch schwierig." [P2]

"Vor allem, wenn es mehrere Möbel waren, habe ich probiert, das Möbelstück zu nehmen, was am weitesten von mir entfernt war, also das, was am weitesten entfernt ist, und dann das nächst-fordere zu nehmen, weil man ansonsten ja das Möbel dahinter hätte stellen müssen." [P7]

"Den Abstand nach hinten zum Beispiel. Entweder, dass ich das Objekt transparent stellen kann, dann kann ich noch nach hinten sehen, wo mein Möbel drin ist. Oder dass ich noch einen Top-View Grundriss habe, wo ich mein Möbel platziere." [P3]

Theme #4

"Ich hab immer versucht, dass sie möglichst parallel zueinander stehen und hab immer dieses Raster angemacht und dann geschaut, dass sie gleich stehen." [P1]

"Das Raster habe ich benutzt, dass eben die Sachen möglichst parallel zu der Wand waren. Das Raster selbst habe ich auch zum Drehen benutzt, dass z.B. die Stühle in der Sitzecke einen 45°-Winkel hatten, sieht einfach sauberer aus." [P6]

"Ich fand es sehr gut, dass man das ganze Raster drehen konnte. Das habe ich zwar nur einmal benutzt, aber da war es wirklich hilfreich." [P8]

Theme #5

"Das du einfach so eine Grundlage hast, auf der du den Raum aufbauen kannst. Vor allem, wenn du noch nicht die mega Vorstellung davon hast, wie es aussehen soll, dann ist so ein Raster immer ganz hilfreich." [P1]

"Es funktioniert sehr gut, es ist noch einmal eine zweite Art, Objekte im Raum zu bewegen, aber ich bin mir einfach nicht sicher, ob ich es wirklich brauche. Vielleicht wenn Smart Guide und Raster gleichzeitig an sind und ich noch Maße habe, dann hätte ich da einen Vorteil, aber eigentlich braucht es das nicht." [P3]

"Aber dieses Raster gibt es auch in ArchiCAD, ich stelle es meistens aus." [P3]

"Ja, sie sind ähnlich wie in PowerPoint. Manchmal regen sie mich dort auch auf. Das heißt, bei PowerPoint ist es genau so, dass sie sich genau darauf fixieren und dann einen Punkt suchen anstatt den zu nehmen, den ich brauche." [P7]

Theme #6

"Ne, ich fand es ist gut in den Hintergrund getreten. Es war schon auch sichtbar, aber nicht dominant. Man hat schon noch gut den Rest auch noch wahrnehmen können. Es war trotzdem sichtbar genug, dass man Sachen daran ausrichten konnte. War eine gute Mischung." [P2]

"Es wäre vielleicht cool, wenn man dem Raster sagen könnte, auf welcher Ebene es ist. Wenn man jetzt sagen könnte „okay, ich möchte, dass die Tischplatte die Grundlage für das Raster ist“, oder dass der Fußboden die Grundlage ist, oder die Wand, also dass man die Möglichkeit hat, das einzustellen, dass man einen Referenzpunkt auswählt und es sich dann von da aus aufspannt. Das wäre eine ganz praktische Funktion." [P2]

Theme #7

"Finde ich gut, dann kann man aussuchen, was einem gerade besser liegt." [P1]

"Eher an dem Raster, weil die anderen Möbelstücke im Raum, zumindest in meiner Herangehensweise, auch daran ausgerichtet wären." [P2]

Theme #8

"Ja genau. Dass man diese Aufgabe für sich selber abschließen kann, in dem man so ein Häkchen klickt. Ich glaube, dass wäre irgendwie befriedigend, wenn man so einen Sessel hinschiebt und dann auf den Haken klickt, und dann steht der da wirklich." [P1]

Theme #9

"Ich fand es ganz gut, auch die Idee, dass man die Kästchengröße einstellen konnte, so konnte man die Entfernungen ganz gut einschätzen. Je nachdem, wie genau man es haben möchte, kann man es dann auch kleiner machen. Das fand ich eine gute Idee." [P7]

"Das habe ich nicht gemacht, ich fand das 10cm Raster eigentlich gut." [P4]

Theme #10

"Ich glaube, dass das gerade für Leute sehr praktisch ist, die Schwierigkeiten mit räumlichen Vorstellungsvermögen haben. Durch das Architekturstudium lernt man das so ein bisschen, sich das auch vorzustellen, deswegen ist diese Hilfestellung vielleicht nicht immer so nötig dafür, wie die Sachen dann so im Raum sind. Aber ich glaube gerade für zum Beispiel, wenn man dem Bauherren zeigen möchte, wie so etwas funktioniert, da kann ich mir auf jeden Fall vorstellen, dass man das in die Hand geben kann und die ein Gefühl dafür bekommen." [P2]

"Wirklich planen würde ich glaube ich nicht wollen mit so einer Software, wenn dann würde ich – wir haben halt unsere CAD- Zeichenprogramme, mit denen wir planen." [P3]

"Wir wissen eigentlich schon immer, was wir uns vorstellen, aber die Leute – unsere Bauherren, oder Menschen, die wir überzeugen müssen – die können sich das oft nicht so gut vorstellen, weil die das nicht jeden Tag machen." [P3]

Theme #11

"Ich fand es mit dem Abmessen etwas schwierig. Das Raster hat schon geholfen, aber ich habe ich dann auch die Raster nicht richtig gesehen." [P4]

C. Study Documents

Welcome Letter

Konstanz, den 24.05.2022

Herzlich willkommen!

Vielen Dank, dass Sie sich dazu bereit erklärt haben, an unserer Studie teilzunehmen. Sie unterstützen damit unsere Forschung maßgeblich! Bevor es losgeht, möchten wir Ihnen kurz vermitteln, um was es bei der Untersuchung geht und welche Rolle Sie dabei spielen.

Ziele und Ablauf der Studie

Im Rahmen der Studie evaluieren wir, wie Augmented Reality verwendet werden kann, um Inneneinrichtung zu unterstützen. Dazu lösen Sie mehrere Aufgaben. Im Anschluss an die Aufgaben bitten wir Sie dann, uns von Ihren Erfahrungen und Eindrücken zu berichten. Vor den Aufgaben gibt es eine Einweisung in die Augmented Reality Anwendung. Fragen zum generellen Ablauf oder zum System können Sie jederzeit stellen.

Um möglichst umfassende Erkenntnisse zu erhalten, zeichnen wir die Studie zusätzlich in Bild und Ton auf. Für diese Aufzeichnungen ist Ihr Einverständnis erforderlich. Im Gegenzug verpflichten wir uns dazu, das Material pseudonymisiert und lediglich zu Auswertungszwecken zu verwenden. In diesem Zusammenhang haben wir eine Einverständniserklärung vorbereitet, die diesem Schreiben beiliegt. An dieser Stelle möchten wir darauf hinweisen, dass wir nicht Sie oder Ihre Leistung bewerten, sondern ausschließlich an der Tauglichkeit der Anwendung interessiert sind.

Zeitrahmen und Entlohnung

Die Dauer der Studie beträgt insgesamt ca. 1 Stunde. Falls Sie sich zu irgendeinem Zeitpunkt unwohl fühlen und Ihre Teilnahme beenden möchten, ist das selbstverständlich auch ohne Angabe von Gründen möglich. Bitte wenden Sie sich dann an den Versuchsleiter.

Nach der Durchführung der Studie werden Sie für Ihre Hilfe mit 10 Euro entlohnt. Wir bedanken uns noch einmal recht herzlich für Ihre Unterstützung!

Arbeitsgruppe Mensch-Computer-Interaktion,
Fachbereich Informatik und Informationswissenschaft,
Universität Konstanz

Informed Consent Forms

Einverständniserklärung

ID: _____

Informationen zur Studienleitung

Studienleiter: Tobias Böhnemann
Institution: Arbeitsgruppe Mensch-Computer Interaktion, Fachbereich Informatik und Informationswissenschaft, Universität Konstanz

Erklärung

Über das Ziel, den Inhalt und die Dauer der Studie wurde ich informiert. Im Rahmen dieser Studie werden in Fragebögen personenbezogene Daten erhoben. Zusätzlich wird die Studie auf Video aufgezeichnet und es werde Audioaufnahmen gemacht.

Hiermit bin ich darüber aufgeklärt, dass die personenbezogenen Daten vertraulich behandelt werden und nicht an Dritte weitergegeben werden. Nach Aufzeichnung werden die Daten durch unser Forscher-Team ausgewertet. Im Rahmen der Auswertung werden auch Abschriften der Audio- und Video daten erstellt. Diese Abschriften werden pseudonymisiert, d.h. es werden sämtliche Hinweise entfernt, die Rückschlüsse auf sie als Person ermöglichen würden. Die Veröffentlichung der Forschungsergebnisse in Publikationen oder auf Tagungen erfolgt ausschließlich in anonymisierter Form und lässt zu keinem Zeitpunkt Rückschlüsse auf Sie als Person zu.

Optionale Punkte *(Bei Zustimmung bitte ankreuzen)*

☐ Ich bin damit einverstanden, dass meine Video- und Bewegungsdaten zusätzlich zu internen Präsentationszwecken genutzt werden können.

Hiermit erkläre ich mich mit den unter „Erklärung“ genannten Punkten und den angekreuzten optionalen Punkten einverstanden:

	Konstanz,	
(Name)	(Ort, Datum)	(Unterschrift)

Hiermit verpflichtet sich die Studienleitung, die Video- und Audioaufzeichnung sowie sämtliche sonstigen gewonnenen Daten lediglich zu Auswertungszwecken im Rahmen dieser Untersuchung zu verwenden:

Tobias Böhnemann	Konstanz,	
(Name)	(Ort, Datum)	(Unterschrift)

Compensation Form

Ich habe an der Augmented Reality Studie mit der App „HomePlanAR“ der AG Mensch-Computer Interaktion teilgenommen und eine Kompensation in Höhe von 10 Euro erhalten:

(Name)	Konstanz, (Ort, Datum)	(Unterschrift)

Ich habe an der Augmented Reality Studie mit der App „HomePlanAR“ der AG Mensch-Computer Interaktion teilgenommen und eine Kompensation in Höhe von 10 Euro erhalten:

(Name)	Konstanz, (Ort, Datum)	(Unterschrift)

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(Name)	Konstanz, (Ort, Datum)	(Unterschrift)

System Usability Scale

Questionnaire taken from [41].

Fragebogen zur System-Gebrauchstauglichkeit

1. Ich denke, dass ich das System gerne häufig benutzen würde.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

2. Ich fand das System unnötig komplex.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

3. Ich fand das System einfach zu benutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

4. Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

5. Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

6. Ich denke, das System enthielt zu viele Inkonsistenzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

7. Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnell lernen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

8. Ich fand das System sehr umständlich zu nutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

9. Ich fühlte mich bei der Benutzung des Systems sehr sicher.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

10. Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

Interview Questions

1. Wie würdest du deine Erfahrung mit der App beschreiben?
2. Wo siehst du Stärken der Anwendung?
3. Wo siehst du Schwächen der Anwendung?
4. Würdest du etwas an der Anwendung verändern?
5. Was war dein Vorgehen dabei, Möbel anzuordnen?
6. Was war dein Vorgehen dabei, in der Grundriss-Aufgabe Möbel zu platzieren?
7. Wie hast du die Hilfsmittel der App in der freien Aufgabe eingesetzt (smart guides/grid)?
8. Wie fandest du die Smart Guides?
9. Auf einer Skala von 1-10, wie sehr haben dir die Smart Guides geholfen, die Aufgaben (die erste, zweite, dritte) zu erfüllen?
10. Wo siehst du Stärken der Smart Guides?
11. Wo siehst du Schwächen der Smart Guides?
12. Wenn du mit dem Konzept schon vertraut warst, haben die Smart Guides deine Erwartungen erfüllt?
13. Würdest du etwas an den Smart Guides verändern?
14. Würdest du etwas an der Visualisierung verändern?
15. Würdest du etwas daran verändern, wie die Smart guides die Möbel beeinflussen?
16. Wie fandest du das Raster?
17. Auf einer Skala von 1-10, wie sehr hat dir das Raster bei der Erfüllung der Aufgaben (bei der ersten, zweiten, dritten) geholfen?
18. Wo siehst du Stärken des Rasters?
19. Wo siehst du Schwächen des Rasters?
20. Würdest du etwas am Raster verändern?
21. Würdest du etwas an der Visualisierung des Rasters verändern?
22. Würdest du etwas daran verändern, wie das Raster Möbel beeinflusst?
23. Würdest du etwas daran verändern, wie du das Raster manipulieren kannst?

24. Wie fandest du es, beide Anordnungs-Hilfen zur Verfügung zu haben?
25. Hattest du eine Präferenz?
26. Würdest du etwas daran ändern, wie die Hilfsmitel genutzt werden können?
27. Kannst du dir vorstellen, AR in einer Form wie in der App in deinem Alltag für Planungsaufgaben zu verwenden?
    a) Falls nicht: Was müsste sich ändern?
    b) Falls ja: Welche Kriterien müssen Anwendungen dazu für die erfüllen?
28. Hast du noch weitere Kommentare?

D. Enclosure

The enclosed USB stick contains a digital copy of this thesis.