Studying Depth in a 3D User Interface by a Paper Prototype as a Part of the Mixed Methods Evaluation Procedure

Early Phase User Experience Study

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Abstract— **A principal characteristic of three dimensional user interfaces is that it contains information in the 3rd axis. Visually, this information is presented as being placed further away from the screen or having depth. A consequence of this is that information can be occluded. Determining the optimal amount of depth levels for specifically sized icons is important in the design of 3D user interfaces. This paper investigates the depth placement of objects of a three dimensional user interface on a tablet device at the early stage of the development process. We present mixed methods evaluation with a paper prototype with a focus on the users' subjective experiences. Users were presented with concepts of different depth levels, with and without 3D objects. The findings indicate that users' preference was for depth levels 3-5. We recommend designing 3D UIs with a controllable depth by starting with a few depth levels and increasing them automatically based on the amount of 3D objects. Also, it is important to give a user a possibility to customize depth levels when needed. This paper provides user preference information on depth for 3D UI designers and developers, especially in the context of a touch screen tablet device.**

Keywords-3D UI; depth; touch screen tablet; paper prototype; user experience.

I. INTRODUCTION

Three dimensional (3D) graphical user interfaces (GUIs) have been studied for many decades and they are still actively researched [1][2][7][10][14]. Typically, interaction with 3D user interfaces involves dealing with information and objects that are spatially organized in three dimensional virtual space. The number of objects, their size and issues of occlusion must be defined and evaluated with users in order to provide a positive user experience. To show large amounts of information, 3D objects are spatially organized at different levels of depth from the 3D camera, or what we call depth levels. 3D research and development is a large and diverse area. Studies exist about appropriate 3D UI metaphors and depth for touch screens in PC environments [1][11]. However, there is not a clear answer for what kind of 3D UI and depth users would actually prefer for touch screen tablet devices.

Cipiloglu et al. [5] present a framework for enhancing depth perception in computer graphics. Different depth cues help users to perceive the spatial relationships between the objects. Earlier studies indicate that spatial organization of information enables efficient access to objects in graphical user interfaces. Cockburn and McKenzie [6] studied the effectiveness of spatial memory in 2D/3D physical and virtual environments and compared 2D, 2.5D and 3D interfaces. However, this experiment was conducted with a PC and mouse and one would expect interaction to be different than with a touch screen tablet device. One influencing factor for a user-tablet interaction with touch screen is the size of the objects, widgets and icons. According to Budiu and Nielsen [3], the target size for 2D UI widgets is 1*1cm for touch devices. In a 3D UI on a tablet device, there are several aspects that can have an influence on how users perceive the space and how they are able to interact with 3D objects in depth through touch screen. This issue has not been studied much in a mobile tablet device context. In a hybrid 2D/3D UI study, Salo et al. [15] found that a large amount of 2D overlay icons decreases the interaction with 3D objects which are embedded in a 3D virtual environment.

This paper presents how we used a paper prototype as a part of mixed methods evaluation procedure at the early phase of the design process to find out the optimal depth levels in 3D graphical user interfaces. Later, we developed a virtual prototype as well in order to see how users' preferences for depth in a 3D UI compare with the results from the paper prototype. Based on the user evaluations with both paper and virtual prototypes, we propose that the depth levels 3-5 could be the most preferable depth for the 3D UI as a default starting point, depending on the system context.

II. METHOD OF STUDY

Paper prototyping is a widely used method in the human-computer interaction (HCI) field, especially in the user-centered design (UCD) process [16]. The aim of the UCD process is to support developing systems that meet the user's expectations and needs. ISO 13407 [8] defines a prototype as: "*representation of all or part of a product or system that, although limited in some way, can be used for evaluation*". According to the Buchenau and Fulton Suri [4], prototypes are "*representations of a design made before final artifacts exist and they are created to inform both design process and design decisions*". Prototypes can range from sketches to different kinds of models, which depict the design as follows

"looks like," "behaves like," "works like" [4]. One benefit of using prototypes is that they can facilitate exploring and communicating propositions about the design and its context.

The paper prototyping itself as a method is not a new idea. Typically, it has been used for improving usability of the UI. Our focus was on subjective user's experiences. When studying user experiences in the early design phase, it is important to use suitable research methods. Although the interest in UX in industry and academy has been high over a decade, there are not enough systematic methods regarding how to evaluate user experiences [17]. Especially, there is a need to develop and use low-cost methods for UX evaluation and utilize the collected information in the early phase of the design and development processes [18]. ISO 9241-110 [9] defines user experience as: "*a person's perceptions and responses that results from the use and/or anticipated use of a product, system or service*". Therefore, user experiences should be evaluated before, during and after the use [17].

A. Concept Design

In the early stage of our research, we did a concept design phase to explore different ideas for the visual design of the 3D UI. In this phase, we drew approximately 100 sketches of different 3D UIs for touch screen tablet devices. From those sketches we selected the most relevant examples for the further design. Among those sketches there were two sketches about 3D UI utilizing depth. The first example illustrates the 3D objects on top of the VE (Fig. 1a) and the second the same example in a customization mode where the grid is visible and background VE is invisible (Fig. 1b). Based on these sketches we created a paper prototype in order to study depth levels for 3D UIs on tablets.
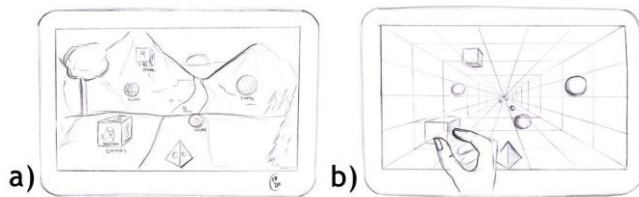

Figure 1. The sketches of 3D UI and objects on A) a virtual environment and B) with a grid background.

B. Evaluation Procedure

We developed a paper prototype in order to study users' preferences for depth levels in 3D UIs on tablets in the early design phase. We used our depth level paper prototype as a part of mixed methods evaluation procedure where we illustrated ten 3D UI concepts to the users by using various types of prototypes. Fig. 2 presents the contents of the whole evaluation procedure. This paper focuses only on the findings gathered from the phase 5: 2) selection tasks A-C (Fig. 2). It was important to introduce participants to the 3D UI topic and show different examples in the evaluation phases 1-4 before the depth level evaluation (Fig. 2). Findings from the phase 1 are reported in [12] and from the phases 2 and 3 in [13].

Evaluation Procedure:

1. 2D/3D icon comparison tasks (tablet prototypes)
2. Four 3D UI Concept evaluations (tablet prototype)
3. 3D UI Use case evaluation tasks (tablet, PC, paper prototypes)
4. Contact and Square UI evaluation (tablet prototype)
5. 1) 3D UI space test (paper prototype)
   Space form selection for 3D UI (examples A1-H8)

   2) 3D UI depth level selection tasks A-C (paper prototype)
   Select the level 1, 2, 3, 4, 5, 10, 15 or ∞ based on which one you prefer or you think you could control:
   - A. Selection Task: Without objects
   - B. Selection Task: With ordered 3D objects
   - C. Selection Task: With unordered 3D objects

6. 3D UI concept evaluations (PC prototype, video)
7. Self-expression tasks (drawing template).

Figure 2. The 3D UI Concept evaluation procedure with mixed methods and the depth level paper prototype evaluation in the phase 5. 2) A-C.
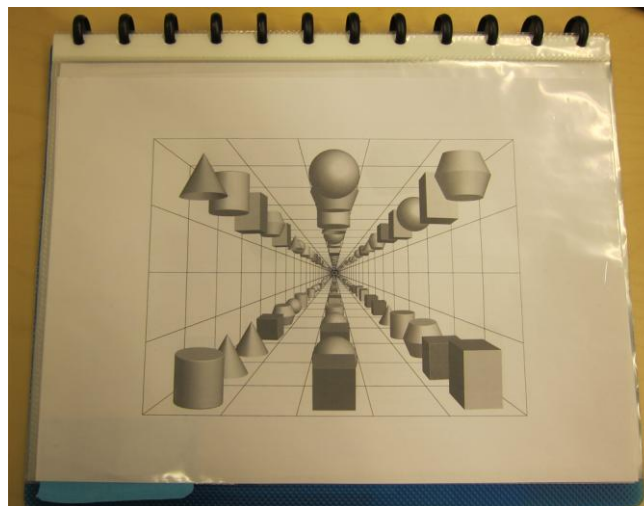

Figure 3. An example page of the paper prototype (Infinity depth).

C. Depth Level Paper Prototype and Selection Tasks

The paper prototype was created in such a way that a UI example would be comparable with commercial off-the-shelf touch screen tablet devices with 2D icons in a 2D UI (e.g., Apple iPad and Samsung Galaxy Tab). For instance, in these kinds of tablets, there are 4*5 application icons presented per screen. Therefore, our grid example included 4*5 icon areas as well. The depth in each level is the space that a 3D icon of an application requires. Fig. 3 illustrates one example page of our paper prototype. The size of the grid was 23.8 centimeters (almost equal to the iPad's screen size, which is 9.7 inches) on a size A4 white paper. Fig. 4 illustrates depth levels without objects (A), with ordered (B) and unordered 3D objects (C). In each selection task (A-C), we had eight depth levels: 1, 2, 3, 4, 5, 10, 15, infinity (∞) and users were asked to select one level in each task (A-C) based on which depth level they prefer (Fig. 2).
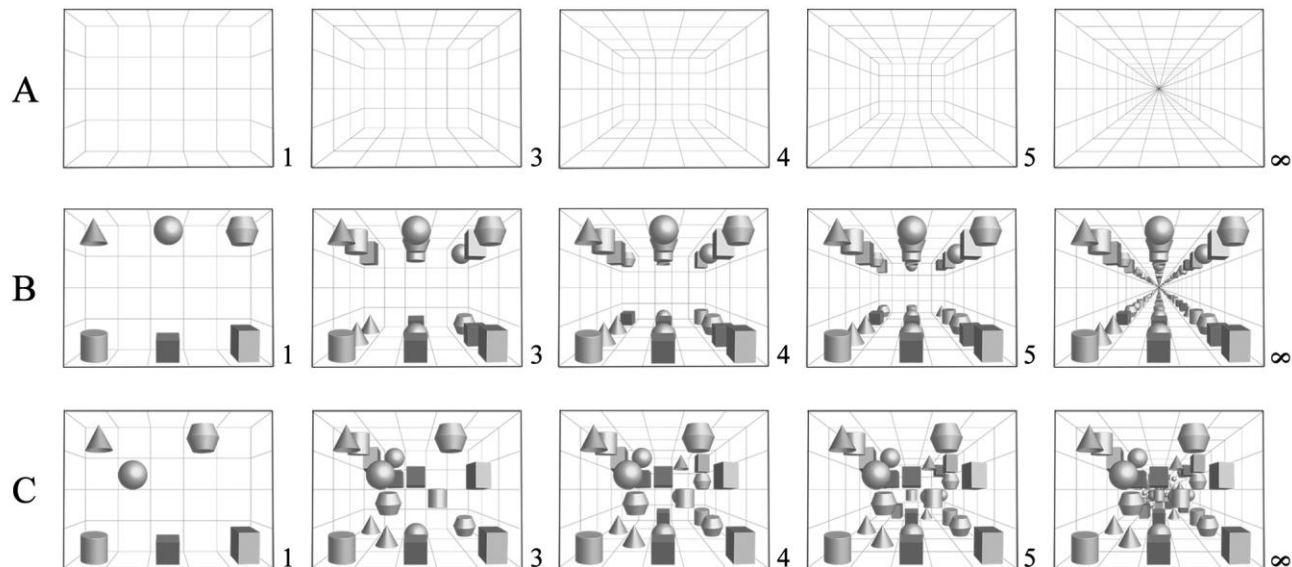
Figure 4.   Example depth levels 1, 3, 4, 5 and ∞ without objects (A), with ordered (B) and unordered 3D objects (C).

We decided to create depth levels with a different set of 3D objects, because of the two reasons. First, in the 3D UIs, objects can be placed anywhere and they can be occluded. Second, in the tablet devices, a user can have a different amount of application icons and widgets.

D.   Participants

The evaluation was conducted with 40 participants (15 female, 25 male), whose age varied from 23 to 52 years (averaging 35) (Fig. 5). Users had prior experience with touch screen devices, either tablets or phones.

III.   FINDINGS

The following Subsections present which depth levels users preferred in the selection tasks A-C (without objects and with ordered and unordered 3D objects) in the 3D UI concept evaluation (Fig. 2). Users' subjective experiences are also cited.

A.   Depth Selections without Objects

Without 3D objects, depth levels 3 (40%) and 4 (35%) were clearly the most selected choices (Fig. 6). According to the feedback, participants made their selections based on how many icons or applications they could place in the space and how they could select them by touching. For instance, depth level 1 was regarded as too plain or tight and only a few applications could be located on the periphery.

One person, who selected level 2, commented: "Here could be 36 icons on sides and ceiling". Participants understood that these icons would occupy the same volumetric space as a 2D icon. Subjects selected depth levels from 2 to 4; because they did not want the background grid to be too small. Participants understood that the background grid decreases when the depth increases. They thought the background area is meant for open applications, which is easily viewable. A person, who selected level 3, said that the

depth depends on the physical size of a finger, the finger will "poke" many icons if the space has too much depth.

Participants who selected depth levels from 3 to 5 justified their selection by referring to memory: "*It would be impossible to remember where some objects are*". The comments on depth levels 10, 15 and infinity were: "*too deep*", "*too small periphery*", "*difficult to control*" and "*cannot use anymore*". One person commented that the infinity level could be a suitable solution for thousands of music files.

Figure 5.   In the concept evaluation with the paper prototype, a participant is selecting the depth level 5 and commenting the 3D object selection.
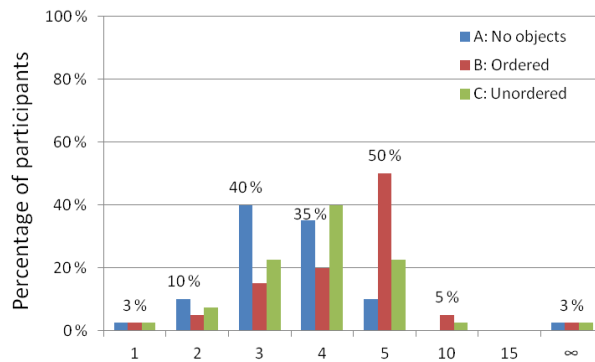

Figure 6.   Participants' selections in the tasks A-C.

B. Depth Selections with Ordered 3D Objects

The comments from participants during the selection of the depth level without objects, revealed how they would place 2D icons on the surfaces. When participants saw depth levels with 3D objects, they perceived how those would appear and be located in the 3D space. When 3D objects were organized in the space, the depth selection was deeper, half of the participants selected depth level 5 (Fig. 6). Users, who selected levels 4 or 5, said that "*from these levels they can remember, control and select icons*". In Fig. 5, a participant is selecting the depth level 5 because in that level he can see and select also occluded objects. One person, who selected level 2, commented that "*If objects would be organized only on the sides, the depth level could be even deeper*".

In this task, people also counted how many objects there would be available for them, and thus, level 2 was regarded as too small. Depth level 1 was regarded as boring. One person, who selected level 5, commented that "*The level 1 shows that I'm poor, I don't have many things happening in my life*". She explained this comment by comparing how many applications she would need in her private and professional life. A person, who selected level 10, said that level 1 would be enough for his mother (e.g., elder and non-technically oriented people). A majority of the comments of depth levels 10, 15 and infinity were negative and related to issues like visual appearance, controllability and memory. One person said: "*It does not feel coequal, because some item is behind the others*". One user thought that depth could increase according to the amount of applications.

C. Depth Selections with Unordered 3D Objects

When 3D objects were not organized, 40% of all users selected the depth level 4 (Fig. 6). Participants, who selected level 4, said that they would like to be able to change their viewpoint or perspective to see behind the objects. Depth levels 1 and 2 were regarded as boring. Some users thought that level 2 causes claustrophobia. Depth levels 3-5 got comments, mainly relating to controllability. Comments on level 5 or more were mainly negative. Users wondered how visible and recognizable the icons would be. They thought that different 3D object shapes could make them recognizable. Some arguments reflect more on the users' personality, for instance, one person selected level 5 and said: "*I like a certain type of chaos*". Another person who selected level 10, said: "*I'm not a minimalist*".

IV. VALIDATION OF THE FINDINGS

This section presents how we later validated UX findings gathered by the paper prototype. We developed a virtual prototype on a tablet device and conducted the similar depth level evaluation with both the paper and virtual prototypes. However, this test did not include the whole 3D UI concept evaluation procedure (Fig. 2).

A. Development of Virtual Prototype on a Tablet

We evaluated our paper prototype method by developing a virtual prototype and conducting the same depth level evaluation with the virtual prototype. In order to be able to conduct a similar evaluation, we designed depth levels with the same visual appearance (Fig. 7). However, in the final virtual prototype, we implemented more depth levels, because we also wanted to study levels from 6 to 20. Another reason for small differences on the appearance was that the virtual prototype was developed by using a 3D program and its camera perspective. This made the background grid appear in a slightly different size in the virtual prototype than in the paper prototype (Fig. 8). Therefore, we measured the hypotenuse of the background grid at each depth level in both of the prototypes and compared them. The difference in the size of the hypotenuse was approximately +/- 1 centimeter. This small difference has been taken into account in the comparison of the results (Fig. 11b).
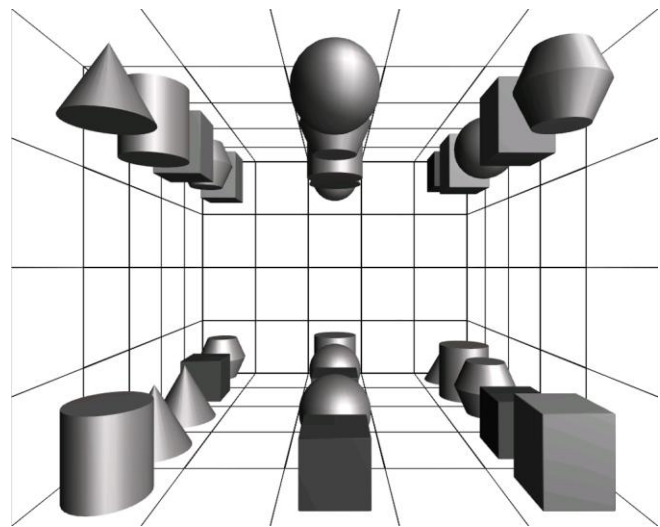

Figure 7.   The screenshot of the 3D UI depth example in a virtual prototype (depth level 5).
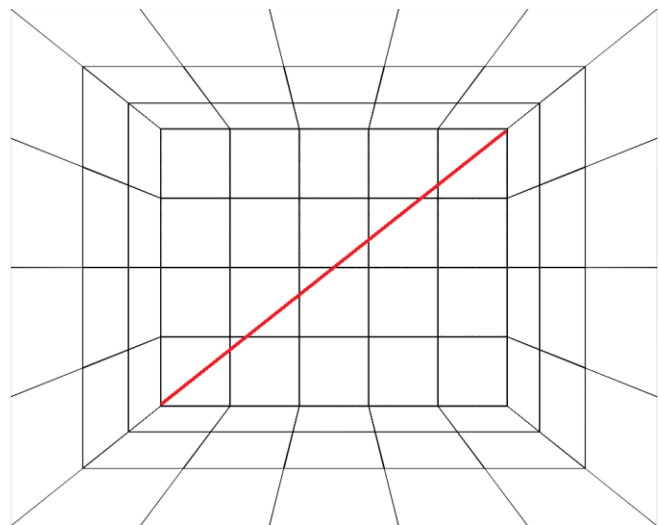

Figure 8.   Size of the hypotenuse of the background grid slightly varied with some depth levels in the paper and virtual prototypes.

The virtual prototype was developed on a tablet device (9,7") and users were able to adjust the depth levels by pressing the screen continuously with one finger and then swiping forward (swipe up) and backward (swipe down) with another finger (Fig. 9). This interaction model was the main difference in comparison to the paper prototype, in which the depth levels were adjusted by turning pages of the binder (Fig. 10a).
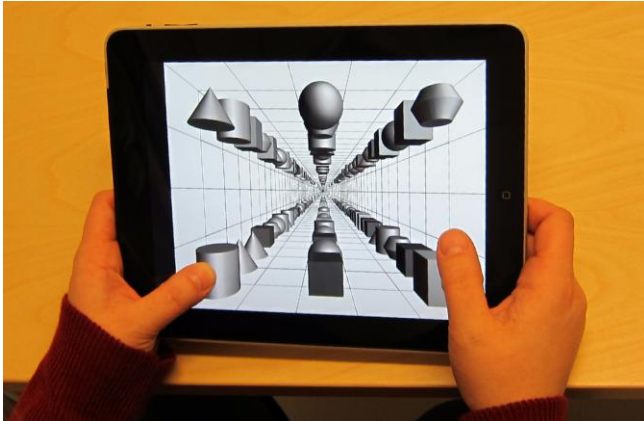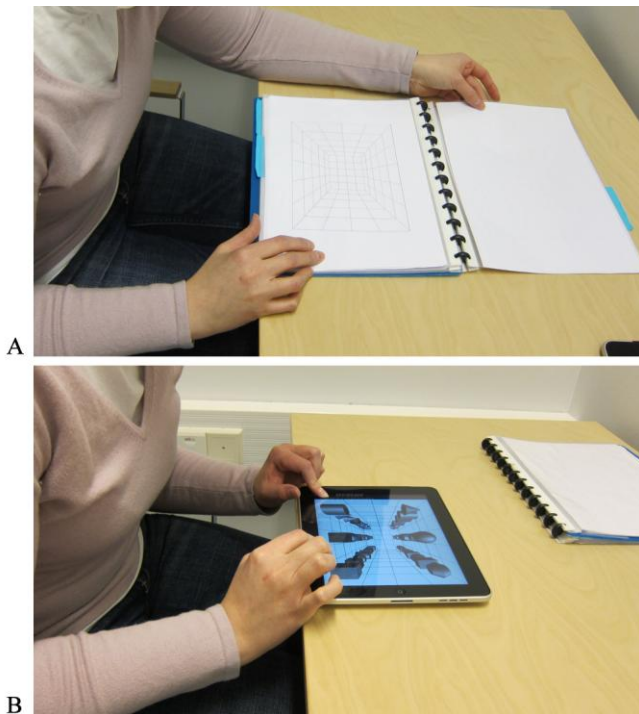

Figure 9.   A virtual prototype on a tablet.

Figure 10. In the validation test, a user made depth level selection tasks A-C with the paper (A) and the virtual tablet prototype (B).

B.   Participants' Selections with the Virtual Prototype

In this comparison test, the same depth level selection tasks were conducted with both, paper and tablet prototypes using a total of 34 participants (Fig. 10).

With the virtual prototype, 18% of users selected level 3 from the example without objects (Fig. 11a). When objects were ordered, levels 4 and 5 were both selected by 18 % of participants. 41 % of users selected level 3, when objects were unordered. The majority of users preferred levels from 3 to 5 in all tasks. Deeper levels such as level 30 and infinity were selected by 3-9% of subjects. These selections indicate the same results that were found by the paper prototype. (Fig. 11a.)

In order to compare results with both paper (PP) and virtual prototypes (VP), we combined selections in certain depth levels (Fig. 11b) according to size of hypotenuse in the background grid. The levels were combined as follows:

- level 4 in VP represents the level 3 in PP,
- levels 5-6 in VP represent the level 4 in PP,
- levels 7- 9 in VP represent the level 5 in PP,
- levels 20 and 30 in VP represent level 10 in PP
- levels 10, 11, 14 are not referable to any levels of paper prototype; therefore, they have been moved to NA (not applicable) category. (Fig. 11b)

Results with virtual prototype (Fig. 11b) support our findings gathered by the paper prototype (Fig. 6). Participants in the both tests preferred depth levels 3-5 (Fig. 6 and 11b).
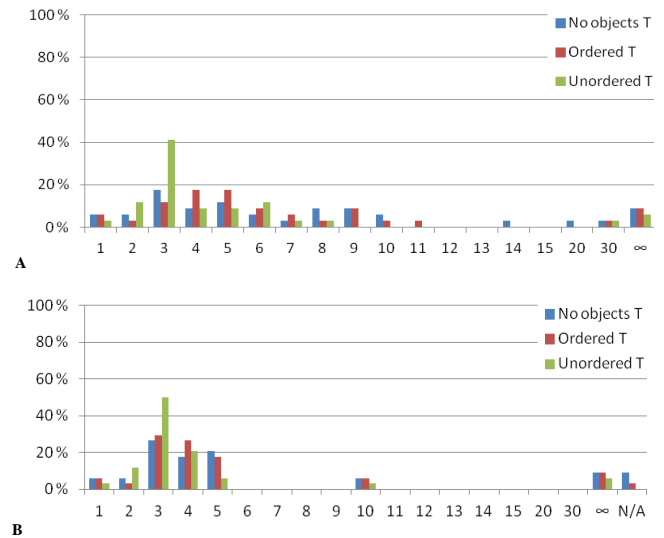

Figure 11. A) Participants' depth level selections with a virtual prototype. B) Virtual prototype's levels combined to paper prototype levels.

V.   DISCUSSION

The depth level experiment in the concept evaluation was made in order to get user feedback for the design of 3D UIs in the early design phase. The paper prototype was developed and used for a certain mixed methods evaluation situation. In this context, the paper prototype proved to be a useful method and enabled us to get user feedback for a specific research topic. Especially in mixed methods evaluation procedures, it is important to use different types of prototypes to illustrate design ideas to the users and then communicate about them. This paper contributes UX

research by presenting how a fast and low-cost method can be used in the early design phase as a part of mixed methods evaluation procedure.

Also the validation test with the paper and virtual prototypes elicited similar results than we found by the paper prototype in the concept evaluation. In further studies, we will use these findings in new 3D UI designs.

VI. CONCLUSION AND FUTURE WORK

This paper presented how users perceive depth in a 3D UI and which depth level they prefer. Results from the depth level selections with paper and virtual prototypes elicited that users preferred levels from 3 to 5. They liked these depth levels because they thought that they can perceive and select all needed applications easily just from one view without a need for hierarchical menu structures and camera view changes. The level 1 was regarded as boring and too simple. Only a few users preferred the infinity level. This level would be interesting to study more with a running application, because preferences for infinity level can be dependent on the content (e.g., music, photos, contacts). Based on the user evaluations with both paper and virtual prototypes, we propose that the depth levels 3-5 could be the most preferable depth for the 3D UI as a default starting point, depending on the system context. Users could also have a possibility to customize the depth levels when needed.

In further studies, we will use these findings in new designs, and then test how users experience the depth levels with an interactive 3D UI on a touch screen mobile device.

The reason for providing this early phase design and UX evaluation information to 3D UI and HCI research fields is to increase the knowledge of conducting UX studies with time- and cost-effective low-fidelity methods.

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