Impact of 3D Virtual Tours on User Experience

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ABSTRACT

3D web technology provides great opportunities by using WebGL to manipulate 3D objects on the web. We see that there is a great interest in using this technology in the real estate business to display residences inside a 3D virtual tour. Our research focuses on whether the 3D virtual tour impacts the user's choices of the apartment and how 3D impacts the user experience. We found, by doing a two-tailed Wilcoxon signed rank test, that there is no statistical significance between the ranking of apartments in conventional 2D and 3D virtual tours. We did find the 3D virtual tour to be more engaging and better at evaluating the size and space of the apartment as well as providing a better understanding of the apartment layout. Also, 2D was found to be more intuitive, more efficient, and overall easier to use than 3D. Our biggest factor that affected the results for this study is that we only acquired 30 participants, and if a replica of this study is going to be conducted, we recommend an increase in participants conducting this research.

1 INTRODUCTION

Today, 3D web technology provides great opportunities and possibilities for the creation of virtual objects, environments, and realities[3]. It helps us create, illustrate, and visualise almost anything and extend new ways of interacting over the web. 3D web technologies have already made a significant impact in trades such as military training[10], education[9], the entertainment industry[1], and architectural designs[5], where residences can be created and visualised as 3D models. One of the 3D web technologies that is currently available, and quite popular, is the technology of creating 3D website content by using Web Graphical Library to display either 3D objects, 3D spaces, or even bigger, entire virtual worlds.
While these opportunities and possibilities exist the inclusion of 3D does not necessarily guarantee a positive impact on web users. Similar studies, where the usage of 3D on the web was explored [15], [19], have been yielding different conclusions regarding whether 3D serves as a superior choice for presenting web content and if it alters user experience favorably. Thus, this study aims to build upon this existing research, offering further insights into what 3D can offer, and whether it may be more suitable than 2D in certain contexts.

Delving deeper into the potential benefits of 3D, this study specifically investigates whether 3D impacts users' choice of certain content when transitioning from a 2D visual representation to a 3D version of the same content. The study selects content to test this impact on, which is currently used in the real world; residences in 3D. This study will therefore research whether people's user experience is better with a 2D or a 3D representation of the residences, and investigate the impact 3D has on users' choice of residence.
To simplify this study, the only type of residence used is apartments. To further clarify the purpose of the study, two research questions have been formulated. These research questions will inspire the development of the data collection methodology. The questions are as follows:

Question 1 "Does a 3D feature positively impact people's user experience?"
Question 2 "Does a 3D feature positively impact people's choice of apartment?"

To address these questions, a platform named Residence Provider has been designed and developed. This platform showcases apartments using both 2D images and 3D virtual tours. Residence Provider is modeled after existing Danish real estate platforms and uses a combination of threeJS, the React framework, and JavaScript to display the apartments in 3D. A research is conducted where participants are introduced to Residence Provider and then explore the available apartments. The data collection methodology involves tracking participant activity on Residence Provider and investigating user experience through a survey.

The primary aim of this study is simple; to provide a comprehensive response to the research questions. The research conducted, as described above, had several findings. One finding was that 3D did not effect the ranking of the apartments, thus apartments with a 3D feature available did not rank better than apartments without the 3D feature. Another finding is that the 3D feature was better at presenting the apartments' layout, it was more engaging, and more useful when evaluating the apartments' size and space over the conventional 2D image feature.

2 REVIEWED LITERATURE

When examining studies on products being displayed in 3D on the web, it is clear that there are existing technologies that have been explored. These studies focus on different aspects of 3D. Some studies focus on sales-centric solutions and assertions, while others look at the efficiency of implementing 3D, and some focus on the immersion level it can provide. We will look into what the studies provide in their discoveries of whether 2D or 3D web technology is better or if at least their participant's interest in 3D is. Additionally, we will look into the existing 3D real estate web platforms that display or create these 3D residence models. Finally, we are investigating other reviewed literature on the subject of what 3D on the web can provide to the user, or if it affects the user experience.

2.1 3D web-based technology Solutions over 2D

There are advantages in the integration of 3D technology, especially in the real estate sector. Utilizing 3D technology has the potential to increase the interest and engagement among customers when interacting with a company brand, as outlined by DeWester et. al.

[11]. DeWester et. al. indicate that companies that use 3D web-based technology can provide a more personal interaction, which is also wanted in the real estate sector when people are looking to buy a home.

3D, fundamentally, can provide a more immersive experience than conventional 2D. This is also the case for 3D web-based technology. As stated by Biggio et. al.[2] 3D web-based technology, or as they say "The immersive web", has a lot of potential because it can give another level of immersion than that of conventional 2D. Additionally, according to Biggio et. al. "Because they (WebXR developers) would endow the user with a real-world interpretive capability through he/she can express him/herself in the interaction in physical augmented space."(p.31). This statement amplifies the idea that 3D on the web can provide a better interpretation of the physical space which users can interact with. In this study, the residences are the physical space.

To be able to include 3D on the web, especially in the real estate sector, 3D still has to be appealing, and easy to use, and customers have to find it somewhat useful. The study from So-Yeon et. al.[15], which is a study closely related in setup and objective to this study, investigates the perceived ease of use and perceived usefulness of 3D web-based technology as well as the sense of presence. They do not conclude that 3D is, in general, better than 2D though they do state findings such as the following: "A web 3D system can more effectively than 2D systems serve market researchers who attempt to assess a target market for products that are customizable or able to be assembed with various shapes, color, or textile choices". The So-Yeon et. al. study also indicates that a web-based 3D system could have significant potential in home-buying decision-making. According to the conclusions of So-Yeon et al., we expect a positive impact on the choice of apartment as our 3D object when our participants explore apartments in 3D. To answer the first research question, we include topics closely related to those of So-Yeon et al., such as ease of use and usefulness, which have shown potential for gathering people's opinions and preferences.

2.2 3D Web-based Technology: The Impact on User Experience

How do apartments displayed in 3D impact users' experience when they have experienced the apartment in 2D? So-Yeon et. al.[15] have already shed light on this question by investigating the impact of 3D technology against conventional 2D technology. There are also other studies adding to the research on how 3D web-based technology impacts user experience. A study by Hao-chuan et.al.[20] explored the effects of 2D versus 3D-based media representations. In the study, students had to learn something new where the visual representations were different (2D and 3D). They conclude "The result implies approximately that different modalities of media representations (2D and 3D) are likely to influence students in different ways." and continue with the following: "Moreover, it would be interesting to look at the differences in 2D and 3D media representations in terms of web usage behavior, attitude, engagement and fun." This shows that there is an effect in implementing 3D, though they do not conclude in which way they were affected but mention several areas like usage behavior and engagement, which will be included in this study.

Another study conducted by Lucian et al. [19] examines the customer experience, perception, and behavioral intentions concerning 2D and 3D web designs. Specifically, they investigate "four dimensions of cognitive absorption (heightened enjoyment, temporal disassociation, focused immersion, and curiosity), playfulness, perceived ease of use, and perceived usefulness.". They have formulated several hypotheses to test the effects of these variables. In summary, their study suggests that 3D does not lead to higher enjoyment, playfulness, or other positive changes. They conclude that 2D designs are easier to use, and ease of use positively influences online purchasing behavior. This contradicts the study from So-Yeon et. al.. We intend to follow the strategy of looking into ease of use, and usefulness, and investigate if the result matches Lucian et al. or if there is a positive effect and follows the results of So-Yeon et. al.[15].

The mentioned studies are not alone in influencing the structure of our survey. For example, Tavanti et. al.[17] mention that we tend to remember content better in 3D, and Scopigno et. al.[14] argue that we have reached a technological era where we can show 3D models on the web in high quality. These studies are also used in the discussion later to see if we obtain similar results.

2.3 3D web-based technology for residence displaying

This study aims to develop a web-based platform with 3D content, and as part of the development process, we've examined similar websites. Websites like **3destateusa[8]**, **Rentrelax[16]**, and **Visuado[18]** specialize in converting residences into 3D models, catering primarily to real estate companies, virtual tour guides, and entrepreneurs. These companies use a variety of technologies to create 3D models of residences. Additionally, they capture 360-degree interior photographs to establish fixed "points", providing users with a comprehensive view of the apartments. Some real estate companies have already implemented the 3D virtual tours, such as **luxuryrealestate**[5], underscoring the growing demand and customer interest in 3D residences within the real estate sector. A noticeable distinction between the above mentioned method of displaying residences in 3D compared to Residence Provider is the use of the 3D model. **3destateusa**, **Rentrelax**, **Visuado**, and **luxuryrealestate** use 3D technology to generate a 3D model, in which serves as the basis for their 360°photos, meaning they have a 3D model that is a simplified version of the house (without any interior) and places 360°photos in the respective places in that model. In contrast, for this study, the 3D model itself constitutes the tour, allowing users unrestricted movement within the space without being confined to fixed points of photos. This decision aims to enhance interactivity and spatial comprehension of the residences. However, it comes with the drawback of potentially sacrificing realism since the apartments are no longer captured with photos from the actual residence but from a constructed 3D model.

Not only do these websites indicate an interest in implementing 3D

tours, but studies also show that 3D implementation is to become more standard and even recommended by researchers. For example, a study by Sherina Zhang [21], thoroughly investigates the idea of incorporating Web 3.0 which is the third phase of the World Wide Web. Sherina Zhang states that Web 3.0 is going to implement 3D VR/XR to consumers of the web and highlight the importance of real estate investors, asset managers, brokers, and developers implementing such features. In general, recommending that the real estate sector rethink how they present residences online as it can create new opportunities for brand building. This is especially relevant and achievable within the real estate sector Sherina Zhang concludes.

3 THE PLATFORM: RESIDENCE PROVIDER

We develop the Residence Provider platform with the capability of presenting the apartments in a layout similar to those of existing Danish real estate websites. We also require apartments to be the content on Residence Provider, therefore, we are investigating available 3D models of apartments online.

3.1 UI and Functionality

Residence provider's user interface and functionality are inspired by the commonly known Danish real estate platforms; Nybolig [12] and HOME[7]. They provide us with a common style and layout for the design of Residence Provider, which most Danish people (which is our main target group for participants) are already familiar with. The design of Residence Provider aims not to favor either 2D or 3D media presentation. As for the design choices for the inclusion of the 3D feature, we have drawn inspiration from real estate platforms that already incorporate 3D, platforms such as those mentioned in subsection 2.3.
Residence Provider aims to function similarly to the mentioned Danish real estate websites, however we have incorporated only essential views and elements for our apartment presentation. In essence, Residence Provider consists of four view pages; the home page, the available apartments page, and the individual apartments page. It is within the last mentioned page that the option to display the apartment in 3D is presented, which is the fourth view page. On Figure 1, the three previous mentioned view pages are shown, (1a, 1b and 1c) and on 1d, the 3D virtual tour feature is shown. The navigation bar is available at all times throughout the view pages available.

3.2 Platform development

To develop Residence Provider we used web technology. We investigated different web technologies with the criteria of it being of an easy 3D web technology implementation, specifically, it needed to include the apartment model´s format which is GLB[1] files. Secondly, the 3D web technology should be able to integrate seamlessly with 2D content presentation, hence it should be adaptable with HTML elements. Next, we investigated different web frameworks and libraries which would make the development process easier and the implementation of 3D apartment models of the same syntax to avoid two or more front end programming languages. Lastly, we looked at ways to increase performance of displaying GLB models online. This concluded in a setup of using JavaScript, The React framework, React Three Fiber, React-drei, and ThreeJS.

3.2.1 ThreeJS. is a JavaScript library. It serves as a gateway to crafting virtual entities on the web by manipulating HTML files using the JavaScript language.
With ThreeJS, we have created a scene in which the apartment model is displayed. We have further included an `Environment` which surrounds the apartment model to make it look like it exists in a real physical location. We also used `Directional light` to make it look like there is an actual sun and the light of the apartments is consistent throughout all of the apartments. ThreeJS is a high-level way of manipulating WebGLs, though to implement it under a common framework and make the implementation process more intuitive, we included React three fiber.

3.2.2 React Three Fiber. (R3F) is an extension of the React framework that integrates with ThreeJS, providing an opportunity for creating 3D models in web applications much easier. R3F has made it easy to manage both regular 2D platform development as well as 3D components in Residence Provider. We believe the choice of R3F decreased the development time considerably.
In essence, React Three Fiber extends the capabilities of ThreeJS.

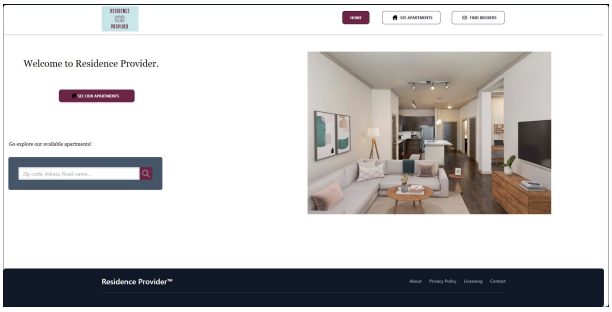
3.2.3 React-Drei:
In order to obtain the functionality wanted for navigation and to be able to load highly detailed apartment models faster, we included the React-Drei library. It provided us with a set of useful abstractions, hooks, and components. Some of the abstractions like `useGLTF` were implemented for better efficiency in loading 3D models and `Canvas Manipulation` was useful in setting up a responsive and scalable 3D canvas´.

3.2.4 The 3D Feature Implementation:
The most advanced page was the 3D view page (see Figure 1d). By leveraging ThreeJS and JavaScript, we implemented several functionalities, allowing for customization of each apartment's needs such as view height and navigation speed. In the 3D view page, users begin at the apartment entrance. Navigation within the apartment is enabled using the W, A, S, and D keys, allowing movement throughout the space without passing through the outer walls. Additionally, we have created a customized collision detection on all the material inside the apartment. This is done by using hooks from React-Drei and Ray-caster from threeJS. The collision is then calculated to measure the distance to any material that is under 1 unit from the camera used. If the camera is under a certain distance from the interacted material, the navigation stops. When mentioning "a certain distance" it is because this distance is one of the customized parameters for each apartment, due to factors such as walking speed and advanced materials in the apartment models. On Figure 2, there is a user-view(2a) and a collision-detection view(2b) in 3D where the collision-edges are shown.

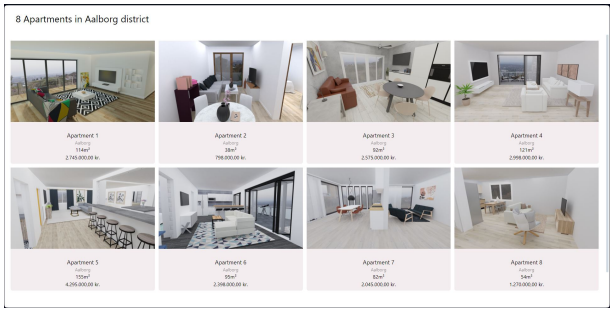
3.3 The Content

The content refers to the apartments that will be showcased on Residence Provider. We create the content so that it is similar to that of these existing real estate websites. On Residence Provider, the content referred to as the 2D content is primarily images and a text

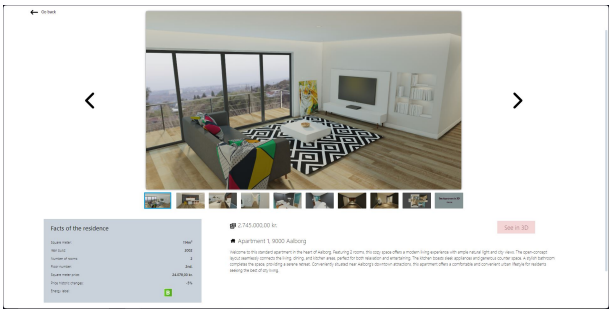
[1]Graphical Transmission Format Binary file



(a) The home view page. Consists of an image, a search field, and a navigational button to available apartments.



(b) All available apartments view page. Each apartment is presented by an image, Apartment name, price, square meter, and zip code



(c) The individual page of apartment 1. The page includes an image carousel, a fact box, the price, and some descriptive text. If there is a 3D model available, the "See in 3D" button is visible.

(d) The 3D view page of apartment 1. This shows the starting position as well as four fixed viewpoint navigation buttons; Kitchen, Living Room, Bath Room, Bed Room

Figure 1: The four available view pages on the Residence Provider platform.

description, complemented by essential details such as residence price and size (see Figure 1c). For the content referred to as the 3D content, it is, as mentioned previously, displayed on a separate view page which shows a 3D virtual space of the apartment selected. The 3D space is designed and crafted using meshes and materials and is handled by the above mentioned programming language and libraries. When users are navigating in the 3D space they have the freedom to explore the residence freely. Additionally, a feature enables users to select predefined views, highlighting key areas of the apartments, namely, the kitchen, the master bathroom, the living room, and the master bedroom in the residence (see Figure 1d).

3.3.1 Validity and quality of the content:

Consistency in the presentation of the apartments is essential. In essence, the images featured in 2D must align with the 3D virtual space to a degree where users perceive minimal differences between the two.

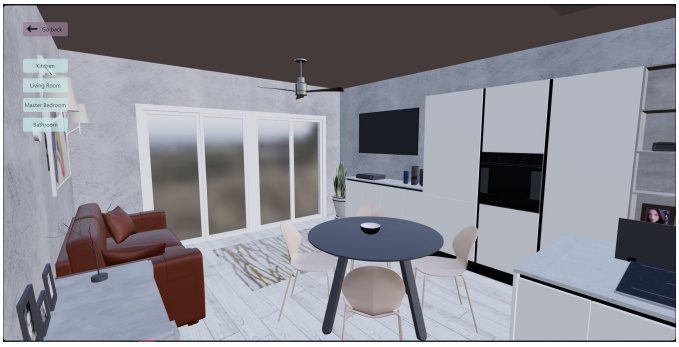
The decision to focus on a simpler form of residence made the implementation of 3D models in the 3D space easier and also made it possible to modify the apartments to improve the overall quality. As a result, the chosen type of residence is being limited to apartments only instead of including houses or bigger estates.

We have chosen eight apartments in total out of numerous collected and investigated as potential candidates. These eight apartments are chosen based on factors like affordability, simplicity, quality, similarity, and availability. Sourced from these online platforms; Sketchfab and CGTrader, which store existing apartment models.

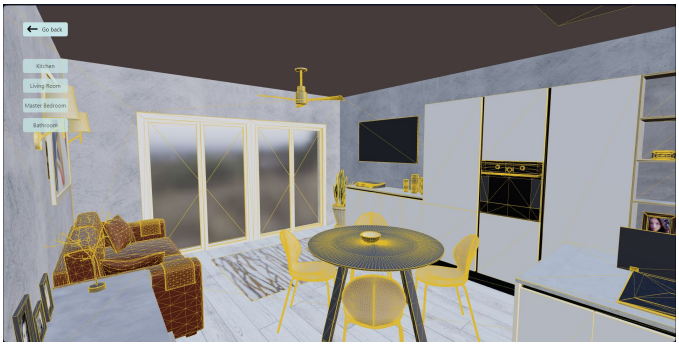
Derived from these online sources, we then further modified the apartments in the program Blender to obtain more realistic layouts where both size and interior changes are made. We created the 2D images from different viewpoints inside the apartment models, to make the 2D and 3D content align. These images have been created in the Blender program. Further details (such as apartment year, square meters, price, etc.) were constructed to match each individual apartment. Regarding the physical location of the apartments, it has been decided that they are available in a local area, the Aalborg district in Denmark, without providing precise addresses. They have been provided with names like Apartment 1, Apartment 2, and so forth, to make them easily distinguishable for participants. The size was determined through measurements conducted in Blender as well, which made the measurement consistent for all apartments. Finally, the descriptive text has been generated by ChatGPT 3.5 which has been fed with information about the individual apartments. As mentioned, all apartments are sourced from online platforms which can be found in Appendix A.

4 METHODOLOGY

Now that Residence Provider has been introduced alongside with the apartments on it, we can explicate the methodology used for



(a) Apartment 3, a view in the living room from their perspective



(b) Apartment 3, a collision-detection view for the processing of distance from the materials to the camera.

Figure 2: Two views in apartment 3; one is the view presented to the participant, the other is a collision-detection view.

answering our research question. This methodology is constructed with the aim to be able to investigate the user experience of the 2D and the 3D features as well as these features impact on their choices of apartments. We have created a procedure that use a combination of the Residence Provider platform and a survey to measure the user experiences of the content presented on Residence Provider.

4.1 Procedure

In the beginning of our research procedure, the participants are introduced to Residence Provider, which displays the home view page, see Figure 1a, and is running on a desktop computer. Additionally, a laptop is available next to the desktop computer, where the survey is presented. As for the procedure itself, the participant starts by getting a short introduction by us, then proceeds to read a more detailed introduction of the tasks and our policies for collecting data. This detailed information is displayed as the beginning of the survey. After reading the introduction, the participants start exploring the apartments on Residence Provider. When the participant have explored all available apartments, they continue the survey. They have access to Residence Provider at all times, thus both screens are available when answering the survey. This setup was determined after completing a small pilot test, as it made it more intuitive for participants to fill out the survey. After the survey is complete, the participants are done with the experiment and the logging data, which have monitored their interaction and time spent on each individual apartment, is collected.

The procedure unfolds as follows:

(1) Research Presentation: Participants receive a brief vocal presentation of Residence Provider.
(2) Detailed Information: Participants read a more detailed introduction and the policies for data collection, displayed at the beginning of the survey.
(3) Exploring Apartments: Participants start exploring the apartments on the Residence Provider platform. They have the opportunity to view all available apartments before moving on to the survey.
(4) Survey Completion: While exploring apartments, participants can refer back to the Residence Provider platform at any time, as both screens are available throughout the survey. This setup aims to make the decision-making process more intuitive.
(5) Post Experiment Process: Once the survey is completed, the experiment concludes. Logging data, which have monitored the participants' interactions and time spent on each apartment, are collected.

If the participant had any issues or questions they were allowed to ask them during the experiment, though if we spotted them having issues we did not intervene.

The setup of apartment availability. In subsection 3.3, we provide detailed information about what the content is. We proceed to describe the setup of the content in this procedure. To measure the difference between the 2D and 3D features, participants are divided into two groups. One group receives a set of apartments with the 3D feature available, while the other group receives the remaining apartments with the 3D feature. There are a total of eight apartments, and each group has four apartments with the 3D feature. For group one, the apartments with the 3D feature are apartments 1, 3, 6, and 8. Correspondingly, group two has apartments 2, 4, 5, and 7. This way all apartments are equally represented in 3D, and we still obtain data for when there is only a 2D feature available.

4.2 The participants

Participants were recruited based on their availability and interest in the study. Thirty individuals participated in the experiment, which spanned four weeks. On average, participants used around 25 minutes to complete the experiment. Participation was anonymous, with only gender and age recorded in order to illustrate the diversity of the study's participants. The diversity of gender is men(22), women(8) and for age it is 15-19(1), 20-24(11), 25-29(13), 30-34(1), 50-54(1), Age not provided(3).

4.3 Measurements

Our survey is constructed to be easy for participants to complete and it had a simple layout so that participants would find the survey intuitive. As for the logging data, it was manually saved after each participant right after the survey completion. As for the survey itself, there is three main categories; ranking of the apartments,

7-point Likert scale and feedback. The survey statements and the feedback questions can be found in Appendix B.

Ranking of the apartments. The apartments are ranked from one to eight, where one is the best and eight is the worst. In the research presentation, the participants where told, that this ranking is based on which apartments they most likely wanted to buy or at least wanted to have a physical tour in. It was observed during the experiment period that most of the time spent on completing the survey was the ranking of the apartments and all participants made use of the possibility to return to Residence Provider if they were undecided on some of the apartments.

7-Point Likert scale. As seen in a similar study ([15]), the usage of a 7-point Likert scale provides valuable insights into participants' opinions. Therefore, we chose that statements should be answered on a 7-point Likert scale (from *Strongly disagree* to *Strongly agree*). Topics such as the ease of use and usefulness of the 2D images and 3D virtual tours, along with general statements related to the Residence Provider platform, have been included. Finally, a series of statements have also been included to compare the 2D and 3D feature. The topics are chosen based on previous studies that emphasize the importance of ease of use and usefulness in measuring user experience. We have divided the survey into four subsets, to better analyse the result of these statements in detail in the next section. The division uses a unique identifier for simplicity instead of giving the full statements. The identifier with its corresponding statement can be found in Appendix B. The division of statements is as follow:

- **Platform**: Platform - Similar, Platform - Intuitive, Platform - Layout, and Platform - Easy to understand.
- **Ease of use**: Layout, Intuitive, Engaging, Convenient, and Overall - Ease of use.
- **Usefulness**: Helpful, Efficient, Size and Space, Quality, and Overall - Usefulness.
- **Comparison:** Clearer representation, More engaging, Better layout, Easier to remember, Overall better experience.

Please notice that for Ease of use and Usefulness statements, there exists 2 of each statement, one for each feature. In Appendix B, the ease of use and usefulness statements are using "X" as the placeholder for the feature. This brings the total to 29 statements in the survey; Platform - 4, Ease of use 10, Usefulness - 10, Comparison - 5.

Feedback. As the last part of the survey, participants are given the opportunity to provide feedback if they encountered any limitations or challenges regarding the usage of Residence Provider, the 2D feature, the 3D feature or on the survey itself. This is included to find underlying reasons for the scores in the survey, and consist of 5 input fields.

5 RESULTS

The results section of this research paper presents the findings from the study, by highlighting the key outcomes derived from the collected data. This section provides a detailed analysis of the data, including statistical tests and visual representations to offer a clearer understanding of the tendencies and patterns observed. The results are used to address the research questions in the discussion section.

To quickly summarize the data collected in this study; there is the survey which holds a ranking of the apartments for each participant. There is also the 29 statements regarding the platform, the 3D virtual tour feature, the 2D image feature and comparison statements between those features. Furthermore, there is the feedback fields about limitations and improvements of the features and the survey. Lastly, there is the logging data of each participant´s activity on the individual apartments. The analysis objectives are to find tendencies in the usage of the 3D feature. The analysis therefore consist of several elements; Statements analysis, Feedback analysis, Logging Data analysis, and Ranking analysis.

5.1 Statistical tests

Before going into the individual analysis sections, we make an overall explanations of the statistical hypothesis tests that will be used. The first test is the Two-tailed Wilcoxon signed rank test[13] (shortened to the Wilcoxon test). We use the average rank procedure and the zero-reduced sample procedure, when conducting the test. The output of the Wilcoxon test is a p-value which should be less than our chosen significance level of $\alpha = 0.05$. The purpose is to be able to reject the following null hypothesis; "The median difference is zero". The one-sample Wilcoxon test will also be used. It has a null hypothesis which is; "The sample median is equal to the hypothesized median, μ". The hypothesized median is equal to the middle value in the scoring range, i.e., $\mu = 4$.

We also use the Friedman test[4] which is done on three or more paired groups. The output of the test is a p-value and the test has the null hypothesis; "There is no difference between the groups". We again use $\alpha = 0.05$ as our significance level. If the null hypothesis is rejected it means one or more of the groups has a statistically significant difference to another group. However, the test does not tell us which groups there is a difference between.

The last statistical hypothesis test we use is Kendall's tau [6] which helps us determine correlations. The output of the test is a p-value and the tau statistic, which is a number between -1 and 1. Tau determines how strongly they are correlated. A tau value of zero indicates no correlation, 1 indicates strong positive correlation and -1 indicates strong negative correlation. In our case, we want to obtain negative values in the tau statistics since rank is best at its lowest value. The null hypothesis of this test is; "There is no correlation", and the significance level is $\alpha = 0.05$.

Interquartile range is used for identifying outliers in the logging data. It finds the values Q1, the 25th percentile, Q3, the 75th percentile, and IQR=Q3-Q1. All datapoints below Q1-1.5·IQR and above Q3+1.5·IQR are outliers. The outliers as well as missing values are replaced using median imputation. We have a small number of datapoints, therefore we impute instead of droping outliers.

All tests and the outlier method are done in python

5.2 Statements Results

The analysis of the statements are done on the four subsets: Platform, Ease of Use, Usefulness, and Comparison

The platform statement scores are visualised in histograms in Appendix D. We see that 20 out of 30 participants score the platform five or six regarding similarity to other real estate platforms, however none gave it a score of seven. the rest of the platform statement scored in general high.

In Appendix C, the full ease of use and usefulness statement sentences and the average score for each of those statements is displayed. The higher the value the better the statement is scored. The red bars are showing the average scores about the statements regarding the 3D virtual tour feature, and the blue bars are showing the average scores for the statements regarding the 2D image feature. Our observations of this figure is that there are some statements that favors 3D and some 2D. To further investigate these observations to see which reflects to be statistically significant, we are conducting the Wilcoxon test on both the ease of use and usefulness statements. The results from the tests is in Table 1.
The null hypothesis is rejected for the Layout, Intuitive, Engaging and Overall - Ease of use statements in the ease of use. Additionally, Efficient and Size & Space for usefulness statements also rejects the H0. The remaining statements accepts the null hypothesis.

Ease of use		
$\alpha = 0.05$	p-value	H0 - result
Layout	0.011	Reject
Intuitive	0.031	Reject
Engaging	0.001	Reject
Convenient	0.724	Accept
Overall - ease of use	0.003	Reject
Usefulness		
$\alpha = 0.05$	p-value	Ho - result
Helpful	0.333	Accept
Efficient	0.029	Reject
Size & Space	0.0006	Reject
Quality	0.063	Accept
Overall - usefulness	0.988	Accept
null hypothesis (H0)	The median difference is zero	

Table 1: Results of the Wilcoxon test on statements from ease of use (Layout, Intuitive, Engaging, Convenient, Overall - ease of use) and usefulness (Helpful, Efficient, Size & Space, Quality and Overall - usefulness)

As for the comparison statements, Figure 7 visualise the number of scores given. From the figure, we observe that most of the scores are clustered in the higher-end for all of the statements, except Easier to remember. We test all of the statements with a One-sample Wilcoxon test to see if there is a statistically significant difference from the hypothesized median which is $\mu = 4$. The result from this test can be seen in Table 2. Only the result from the Easier to remember statement has been accepted.

Comparison		
$\alpha = 0.05$	P-value	H0 - Result
Clearer representation	0.000068	Reject
Engaging and interactive	0.000005	Reject
Better understanding of layout	0.000024	Reject
Easier to remember	0.179879	Accept
Overall better experience	0.000023	Reject
null hypothesis (H0)	The sample median is equal to the hypothesized median	

Table 2: Shows each formulation of the comparison statement, their p-value and results from the test

5.3 Feedback Results

As to the Feedback analysis, we conduct qualitative coding where we code the feedback and categorize it by statements involved. Then we cross-reference the code with the participants answers to the relevant statement. This procedure is done for all feedback questions in the survey to see if there is a pattern between feedback and the rest of the survey answers, or if the feedback can provide further insight into the results of the survey.

The result from the coding can be seen for each of the five feedback questions in Appendix F, where the participant number, feedback, code, and a score if the code was related to a statement. From our coding we found statements with code Intuitive and Size&Space to be the most occurring and gave feedback that was similar to each other. Five out of six Intuitive feedback are regarding a lack of instruction about the navigation controls in the 3D feature. There is also 17 coded as Size&Space, primarily regarding difficulties in understanding the size of the rooms and furniture, especially in 2D. The total number of feedback provided was 100. Out of the 100, 45 answered no to if they experienced any challenges, limitations, areas they wished were better captured, or misunderstandings with the survey.

5.4 Logging Data Results

The logging data analysis consist of several smaller analysis to see tendencies across time spent on the features.
First, we investigate if participants tend to spend most time in their best ranked 3D apartment least in the worst ranked 3D apartment. We therefore found each participants ranking of the apartments where only the 3D virtual tour was available and the corresponding time. By conducting a Friedman test on the time spent in 3D on their highest, second highest, third highest, and forth highest ranked apartment, we obtain a p-value of 0.37. The null hypothesis is accepted, i.e., there is no difference between the time spent across the 3D ranked apartments.

Second, investigating if there is a difference in time spent in 2D *with* the 3D feature available and time spent in 2D *without* the 3D feature available. By conducting the Wilcoxon test, we obtained the p-value 0.01 which reject the null hypothesis, and we do observe a statistical significant difference. We then acquire further insight into what the difference is by calculating the median for the two

sets. The median time spent in 2D with the 3D feature was 30 seconds, and the median time spent in 2D without the 3D feature was 34 seconds, meaning, on average participants spent 4 seconds more when they did not have the 3D feature available.

Third, we look into if participants time spent in 3D are different from time spent in 2D where the 3D feature was available. By doing the Wilcoxon test, we get a p-value of 0.002. This reject the null hypothesis and there is a difference in time spent in 2D with 3D compared to 3D. Again, looking at the median, we have the 30 seconds for 2D with 3D and 38.5 seconds for 3D, meaning, on average, participants spent 8.5 seconds more in 3D than 2D with the 3D feature available.

5.5 Ranking Results

We are interested in identifying tendencies and patterns in our dataset regarding the rankings of the apartments. We begin by calculating the average rank for each apartment when the 3D view was available and when only the 2D view was available. This is illustrated in Figure 3. It is important to note that the best average score is the lowest value since participants ranked the apartments from one (the best) to eight (the worst).

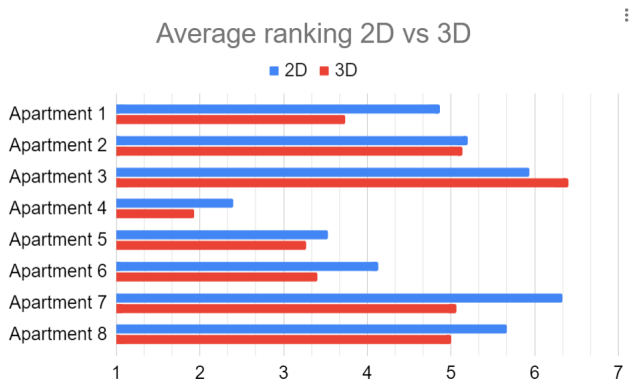


Figure 3: Average ranking of the apartments in 2D image feature only and 3D virtual tour feature available.

From Figure 3, we aim to observe how many of the red bars, representing the 3D view, are lower than the blue bars, representing the 2D view. This would support our second research question. As shown in the figure, this is the case for all apartments except for apartment 3, which was scored higher when only the 2D view was available. These observations are further investigated by using the Wilcoxon test with $\alpha = 0.05$. We have obtained a p-value of 0.0602 and therefore we accept the null hypothesis. I.e., the difference we observe is not statistical significant.

We also know that, in the process of evaluating an apartment, other factors beside the media representation could potentially influence the ranking of the apartment. Therefore, we use the Kendall's tau to determine both direct and indirect correlations between time spent in 2D, time spent in 3D, price of the apartment, size of the apartment and number of images available. Figure 4 shows the different correlations and Table 3, shows the output from the Kendall's tau.

The results from Kendall's tau shows that the size and price of the apartment negatively correlates with the ranking order. This means that higher prices and larger apartments are associated with lower ranks, which is favorable. Additionally, both time spent in 2D and time spent in 3D correlates to the ranking and the same goes for the number of images. Those mentioned also provides with a negative tau statistic. Number of images did not correlates with time spent in 2D and neither did the size of the apartments to time spent in 3D.

6 DISCUSSION

Now that we have presented the results from our study, we can discuss the outcome. Our discussion is looking into the results from the rankings, statements and log data to evaluate the user preferences of the features. We are also going to discuss the differences these features had on the user experience regarding the ease of use and usefulness statements. We also want to find out if these results are following the results from similar studies previously mentioned. We also include insights into the limitations and challenges throughout the analysis as well as the data collection procedure. Finally, we tend to answer our research questions.

When we interpret the results from our different analyses they each provide something specific which can help us answer our research questions. The statement and feedback results can provide information about user preferences as well as user experience. To provide further insights into the user experience we discuss our logging data results. The ranking results are more problematic to analyse given the numerous factors that can influence the ranking decision, though by combining the interpretations of statements, feedback, logging, and ranking, we will be able to answer our research questions.

6.1 Statement Interpretation

The statement Platform - Similar did not score seven even though most of the scores were high. We believe that is due to our platform's simplicity. However, we do believe that Residence Provider do not limit the participants when they evaluate the apartments since the rest of the platform statements were scored five, six, and seven. This indicates a generally positive attitude towards the Residence Provider.

From our results about the 3D virtual tour feature (both from Ease of use and Usefulness), we found that the 3D feature gave a better understanding of the layout, was more engaging, and provided a better understanding of the size and space of the apartments than 2D did. This suggests that our participants preferred having the 3D feature available when evaluating the apartments. When looking at the comparison statements, it also shows that the 3D virtual tours did provide a clearer representation of the apartments than 2D. Furthermore, the result for the comparison statement about the 3D feature providing a more engaging and interactive experience supports the result from ease of use. The same connection is seen for our layout statement interpretation and the Better layout comparison statement. And the result of the last statement in comparison, that the 3D feature did provide an overall better experience, sums up nicely the impression we believe that the 3D feature provided.

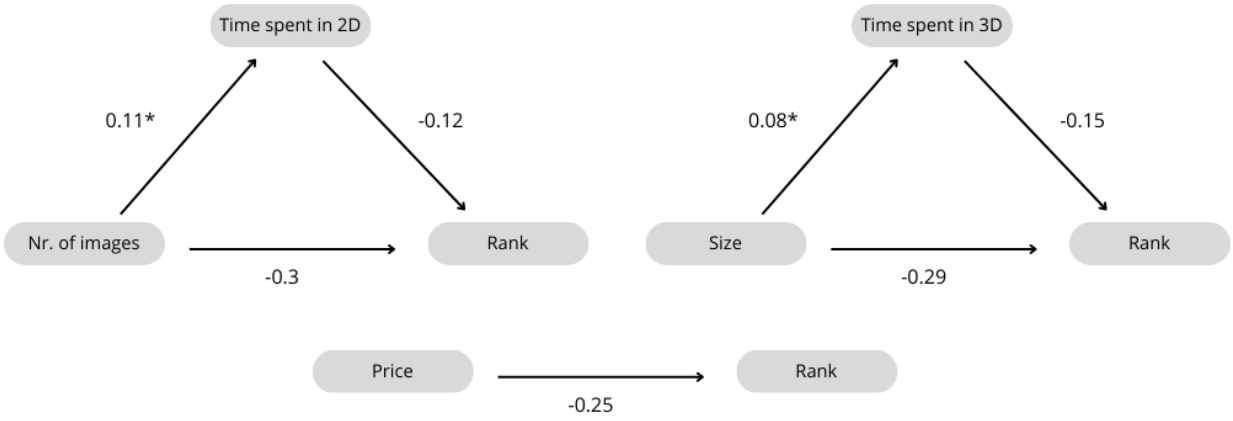


Figure 4: Shows the variables and their direct and indirect correlations. The values displayed next to the correlations are the tau's statistic, and if the value is marked with a star the hypothesis is accepted.

Kendall's tau				
The independent variable	The dependent variable	p-value	tau's statistics	result
Number of images	Time spent in 2D	0.1	0.11	Accept
Time spent in 2D	Rank	0.049	-0.12	Reject
Number of images	Rank	1.88e-9	-0.3	Reject
Size	Time spent in 3D	0.19	0.08	Accept
Time spent in 3D	Rank	0.021	-0.15	Reject
Size	Rank	7.43e-10	-0.29	Reject
Price	Rank	1.00e-7	-0.25	Reject
null hypothesis (H0)	There is absence of association			

Table 3: Results from the Kendall's tau on correlation

However, it does not mean that the 2D feature was insufficient or provided a poor experience. The 2D feature did score higher in how efficient the feature was in evaluating the apartments and it was more intuitive to use than the 3D feature. We believe this to be a common trade-off of 3D features in general, since 3D tends to be a more visually stunning tool than an efficiency tool and therefore being better at, for example, displaying apartment layout or evaluating its size and space, thus being less efficient and intuitive than conventional 2D. The result from the Overall - Ease of use statement is scored higher for the 2D feature which we tend to see as a good characteristic for the 2D image feature.

As to the discussion of which feature provides the better user experience, is not easy to decide. The results observed have made us believe that even though 3D does provide a positive effect in some areas and seems to improve the ranking of the apartments (see Figure 3), it cannot replace the 2D image feature entirely. As stated by Participant 12 "The 3D tour was a good supplement, but the 2D images are essential, especially the floor-plan". Here, they refer to the 3D virtual tour as being a good supplement and therefore not a replacement, and both this statement and our results we have obtained, leave the impression that even though the 3D feature is good, the 2D feature is still gonna be preferred if the choice did come to either have 3D only or 2D only features.

As for the rest of the Ease of Use and Usefulness statements; Convenient, Helpful, Quality, Overall Usefulness, we do not have a statistically significant difference in preference of feature. Which means 2D and 3D were equally good or equally bad. However, as most participants gave the statements a high score, we believe the features to be equally good regarding these statements.
As to the "Easier to remember" comparison statement it did also not yield a statistically significant difference, which can mean multiple things. It is not expected for the participants to remember all apartments with the 3D feature available, though since the participants did score statistically higher in the rest of the comparison statements, we would see an interest in those apartments which then indicates that would make the apartments easier to remember. Furthermore, it might just reflect that, which of the apartments have the 3D feature, does not matter, only that when it is there, it does provide a clearer representation, and a better experience.

6.2 Feedback Interpretation

From the intuitive coding, we see that there was a challenge in the 3D virtual tour navigation controls, given that there was no clear guidance provided on the platform. From the coding, we see that the layout was, in general, difficult to understand in 2D and therefore the floorplan was a necessity to gain the full overview.

Another common feedback regarding the features is that it was difficult to imagine/understand the size of and the distances inside the apartments. Though this feedback was mostly directed towards the 2D feature since 9 feedback were given for the 2D feature and only 1 for the 3D feature. Two participants stated the challenges with the size and space of the apartments; Participant 20, Figure 8, "I had an easier time getting an idea of scale, in the apartments featuring the 3d feature" and Participant 4, Figure 8, "Yes, it was quite hard to imagine how small or big the individual room was, even though you had furniture for comparison.".

Some feedback provides insight into the navigation control of the 3D. Participant 20, Figure 9, gave feedback as such: "I would have liked an overlay or the likes that told me the controls. If i wasn't told i could move around with WASD, i would most likely only move around with the buttons on the left side". Furthermore, some participants do mention improvements in the environment in which these apartments are placed. One of them is participant 17, table Figure 10 who, regarding areas that could be better showcased in the 2D, states "The background looking out of the windows and balconies, instead of it being blurry.".

6.3 Logging Data Interpretation

We did two Wilcoxon tests; one for the difference in 3D time spent and 2D time spent, and one for 2D time spent where the 3D was and was not available.
The first results to discuss is from the Friedman test. We had a premonition that there might be an increased time spent in their highest-ranked apartment with the 3D feature available, though this is not the case. However, this result indicates that no matter the time spent in each of the apartments with the 3D feature it did not require additional time to evaluate the apartments.

Second result; time spent in 2D with versus without the 3D feature. since there is a statistical difference means that there might be less interest in using the 2D feature when the 3D feature is there to be explored. It also suggests that the 3D feature provides insights into the apartment that reduce the time spent understanding it. Consequently, without the 3D feature, participants might need more time on average with the 2D feature alone. However, since the difference is only 4 seconds, this interpretation is questionable.

As to the last result, the 3D feature did statistically use more time, on average, than 3D with the feature available. This can be interpreted two-ways; using more time in the 3D feature indicates more interest in the feature and therefore also fits the result of the 3D feature being more engaging than the 2D. Though it also could indicate to be more time consumable and is therefore less efficient to use when evaluating the apartment which is the case stated in subsection 6.1.

To reflect on the data collection procedure of logging, was quite inefficient and could be much more optimised and include other surveillance measurements like the order of which apartments they entered. we do know that not all apartments were explored in 3D though the reason for that might have been highlighted more clearly with a more optimised and comprehensive version of our current method of collecting logging data. Another clear example of a lacking data collection strategy, is the observation we saw during the experiment by participants tend to spend more time on the first entered apartment, inside the 3D virtual tour specifically. This increased time is believed to be due to a learning curve, as participants were not given a direct introduction to the navigation controls. This is supported by feedback from Participant 20, who stated, "I would have liked an overlay or the likes that told me the controls. If I wasn't told I could move around with W, A, S, and D (keyboard keys), I would most likely only move around with the buttons on the left side."

6.4 Ranking Interpretation

The ranking result did not favor our study's objective to answer the research questions, since accepting the null hypothesis and therefore saying that there is no difference between the ranking of apartments in 3D and 2D. However by looking at Figure 3, it does seem so, and therefore, It would be interesting to see if a bigger set of participants would result in a rejected null hypothesis.

besides that discovery, we also found which variables correlate to the ranking from the result of Kendall's tau. here we found a total of 5 variables correlate to the ranking score, which is the number of images, Time spent in the 2D and 3D features, and the size and price of the apartments (see Figure 4 and Table 3 for the results and the difference variable relations). The result does make sense given that all of the above mentioned variables are good candidates for correlation to the rankings. For size, price, and number of images, they show more potential to affect the rankings than time spent in 2D and 3D given the lower tau statistics and much lower p-value. As for the accepted hypothesis, it was quite surprising. It would be logical to assume bigger apartments would correlate to time spent in 3D and the same goes for number of images to time spent on the 2D image feature. We believe that size does not correlate with time spent in 3D is that no matter size (to a degree of course) it still takes a certain amount of time to process and no matter if the apartment is $38m^2$ or $155m^2$ it still takes time to explore the apartment. As for the number of images, we can only guess it to be reflective of the interest in the 2D image feature not being that great. Since an apartment is limited to several smaller rooms and not that many square meters, a finite list of interesting images is expected. Therefore, an apartment on $38m^2$ does have a lower number of images than the $155m^2$ and even if the smaller apartment had more images, we believe those would be of no use and the participant only spent a fixed amount of time looking at images no matter the number of them.

6.5 Similar studies' result

The study by Hao-Chuan et al. [20] did not find any statistical significance indicating that 3D had an effect, meaning they could not

measure any statistical difference between 3D and 2D usage from their 23 participants. In contrast, our study has found some statistical significance, providing evidence that our 3D virtual tour affected participants, particularly in aspects such as layout presentation, evaluation of the sizes and spaces of the apartment, and higher engagement towards the 3D. The study from Lucian et. al.[19] found that, as previously mentioned, 3D was less easy to use than 2D which is similar to our findings, that 2D was more intuitive than 3D. Though Lucian et. al. do find that websites with a 3D design lead to increased curiosity, which is something we did not look at directly, but something similar since our participants were more engaged when using the 3D virtual tour. In contrast to Lucian et. al.'s study is the So-Yeon et. al.[15] study which did find 3D to be significantly higher when measuring perceived ease of use and perceived usefulness. Though when comparing our results we only found 3D useful for participants when they evaluated the apartment's size and space.

We also mention the study from Tavanti et. al.[17] where they concluded it was more performative to do tasks in 3D that required spacial memory tasks. Our study, again from a different aspect, did not find 3D more helpful than 2D and that apartment with the 3D feature available was not easier to remember when they ranked the apartments, which somewhat contradicts this study. Scopigno et. al.[14] talked about the web is ready to display 3D web models in high quality. Since there is no statistically significant difference in the visual quality between the 2D feature and 3D feature and the scores are quite high indicate that 3D, as well as 2D, is presenting to a certain adequate standard of quality. This is a good sign and follows the conclusion from Scopigno et al.

Overall, comparing our results with those of other studies makes it challenging to draw definitive conclusions about whether 3D is superior to 2D and in what specific ways. The question of whether and how 3D is better than 2D involves many factors, making it difficult to arrive at a unified conclusion. Even though there are differences in methodology between all above mentioned studies, these studies are all trying to contribute to the same subject. These results, including ours, do contribute to this area of research, though it means the results are not easy to streamline across other similar research therefore we believe the idea of 3D being better than 2D is case-specific and depending on the 3D model to be displayed and what the developers wants 3D to be better at.

6.6 The research questions answered?

In terms of our own research, we tend to answer the research questions that have been presented. The first research question is:
"Does a 3D feature positively impact people's choice of apartment?"
The short answer is a small yes, though it depends on how you determine positive impact. We did not find the average rankings of the apartments to be better when the 3D virtual tour feature was available, which is a negative. However, we can conclude that the 3D virtual tour feature has had some positive impacts on ease of use and usefulness. The question is then; if the 3D virtual tour impacted the apartment choices by being more engaging and better at visualizing apartment layouts than 2D, does that imply it only has a positive impact if it possesses these characteristics? We cannot definitively state that a 3D feature positively impacts people's choices based on a single study with a limited set of statements and 30 participants. Nonetheless, our study indicates that the 3D virtual tour developed and used on Residence Provider positively impacted the apartment choices when our participants viewed these apartments from a real estate perspective.

As for the second research question:
"Do people have a prefer the usage of the 3D virtual tour or the 2D images?"
Our participants showed a preference for 3D when evaluating the comparison statements; they found 3D to provide a clearer representation, be more engaging and interactive, did offer a better understanding of the apartment layouts, and provide an overall better user experience. As stated in the previous research question, 3D did have some better characteristics than 2D, in engaging, layout, and size and space evaluation. though 2D did triumph when looking at efficiency in ranking the apartments as well as being the more intuitive feature and overall is easier to use than 3D. As for the more subconscious choices, the logging data, the 3D virtual tour feature was spent more time on, on average, and it did correlate with the ranking of the apartment but so did the time spent in 2D. Overall it does not seem to be the case that the participants prefer either of the features more, though, the participants did more appreciate the presence and option for a 3D virtual tour feature. We also refer back to a previous statement from Participant 12; "The 3D tour was a good supplement, but the 2D images are essential, especially the floor-plan".

6.7 Challenges

Throughout this study, challenges have emerged from both the development of the platform and during the data collection. We are also seeing these challenges in some of the similar studies.

6.7.1 Data Sample. Our biggest factor in this study's outcome has been the number of participants obtained (N=30). As the challenges from the Hao-Chuan et. al.[20] study, they too found that number of participants to be a crucial factor in analysing their results (N=27) and therefore made it difficult to interpret more precise, just as we have. Another challenge regarding the data sample is the diversity of participants (see 4.2) which is fairly to say that two dominant age groups (20-24, 25-29) are represented. This is also seen in Lucian et. al.[19]. This dominant representation can provide insight into a specific group of people though it was not our aim, and if we did obtain more participants with a higher diversity in age, the data might produce an entirely different result, which could be interesting to look into. It is therefore recommended that to replicate this study, a significant increase in participants is encouraged with a focus on age diversity.

6.7.2 the problem's complexity and how it is measured. The complexity of the problem has been a challenge since we have tried to find what exactly impacts people's technology preferences and how it impacts them. For example, So-Yeon et. al. [15] explain the different influence possibilities by either using a direct or indirect effect of perceived ease of use and perceived usefulness. In our case,

we tried to find out what aspects of the ease of use and usefulness were better in 3D over 2D. Even though we found some aspects, we are far from all the angles of possible impacts. In essence, the problem is too complex for a single study, and consistency in possible impact and how they impact users are essential throughout multiple studies to find out if this case is just another small observation or if it does provide an idea of the possible impact 3D can have and in which areas it is better at than 2D.

The complexity of this research has shown a challenge, as we sought to determine what precisely impacts people's technology preferences and how these impacts manifest. For example, So-Yeon et al. [15] discuss some influence possibilities, including the direct and indirect effects of perceived ease of use and perceived usefulness. In our study, we aimed to identify which aspects of ease of use and usefulness were better captured in 3D compared to 2D. While we did identify some aspects, we did not cover all possible angles of impact. Essentially, the problem is too complex for a single study. Consistency in the identification of potential impacts and how they affect users' technology preferences across multiple studies is crucial to state whether this is just another small observation or if it provides a clearer idea of the potential impact of 3D and the areas where it excels over 2D.

6.7.3 Limitations. The challenge of obtaining participants was due to a limitation of equipment since Residence Provider platform requires a lot of computation, and the experiment setup required two computers. Another limitation has been the availability of apartments online since they had to be adequate in visual quality, and size. Even now the apartment's sizes differ from 38 square meters to 155, for a replica of this study, trying to obtain more apartments that differ less in size might provide more accuracy in technology preference rather than the apartment's size or price.

7 CONCLUSION

In this study, we have examined the usages and impacts of a 3D virtual tour feature over a conventional 2D image feature. by using the Residence Provider platform we gathered 30 participants who saw and ranked apartments in 2D plus 3D and 2D only. After ranking the apartments they answered a survey which was constructed of several statements and feedback items, with the intent of finding reasons for their rankings and preferences in technology usage. What we discovered from our results we have interpreted and tried to answer our research questions.

A conclusion from the study consists of several smaller findings. One is that the average ranking of apartments seemed to be better for almost all apartments available with the 3D feature, though we discovered no statistical significance between the rankings. We know that several factors Such as Prize of the apartment and the size of the apartment correlated to the rankings and that some of the reasons for an interest in 3D might be because the 3D virtual tour feature was more engaging and did better at present the layout of the apartment and evaluating the size and space of the apartment than 2D. Likewise, we also did find 2D to be the better choice when comparing how intuitive these web technologies are and are overall easier to use and more efficient when evaluating the apartments. We found a correlation between time spent on the features and the ranking of apartments, and the number of images does not correlate to time spent looking at the 2D images. Finally, we found that the 3D virtual tour did have a higher median in time spent than the 2D images.

We also found no statistical evidence on whether 2D was more helpful or provided a better visual quality over 3D, or vice versa. The same goes for how convenient the features are over the other. This is one of the challenges we have found due to a low number of participants which is for future work if a replica is to be made of this study.

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A LIST OF APARTMENTS FROM ONLINE SOURCES

Apartment 1	https://sketchfab.com/3d-models/apartment-8754655f3a314e53bdd196eee85d43d5
Apartment 2	https://sketchfab.com/3d-models/2-bedroom-apartment-winbranch-complex-1c7620bb368849f4971b9924fc8ce233
Apartment 3	https://www.cgtrader.com/free-3d-models/interior/house-interior/3d-floor-plan-apartment
Apartment 4	https://sketchfab.com/3d-models/apartment-2-by-alina-5e3b8e143092479aafafb5cd72ad212f
Apartment 5	https://sketchfab.com/3d-models/apartment-fe5c1be58c704f23886ed0152be2cda0
Apartment 6	https://sketchfab.com/3d-models/modern-apartment-93cc01fa20724e6d8c27b842ab1e85fd
Apartment 7	https://sketchfab.com/3d-models/apartment-dd87ebbf12644e75a17ca01fa894eb81
Apartment 8	https://sketchfab.com/3d-models/bilocale-apartment-37-textures-262d59c98c794569a3876d1c9f13ede0

B SURVEY STATEMENTS AND THEIR UNIQUE IDENTIFIER AND FEEDBACK QUESTIONS

Platform	
Platform - Similar	How much do you think Residence Provider is similar to other Danish real estate websites?
Platform - Intuitive	Residence Provider is intuitive.
Platform - Layout	Residence Provider has a good layout.
Platform - Easy to understand	Residence Provider's features are easy to understand.
Ease of use	
Layout	The X feature made it easier to understand the apartment's layout.
Intuitive	The X feature was intuitive to use.
Engaging	The X feature was engaging.
Convenient	The X feature made it convenient to compare different apartments.
Overall - Ease of use	Overall, I found the X feature easy to use.
Usefulness	
Helpful	The X feature was helpful for evaluating the apartments.
Efficient	The X feature made the evaluation of the apartments more efficient.
Size and Space	The X feature provided useful insights into the size and space of the apartments.
Quality	The X's visual quality was excellent.
Overall - Usefulness	Overall, I found the X feature useful.
Comparison	
Clearer representation	Listings with the 3D virtual tour feature provided a clearer representation.
More engaging	Listings with the 3D virtual tour feature were more engaging and interactive.
Better layout	Listings with the 3D virtual tour feature provided a better understanding of the apartments layout.
Easier to remember	Listings with the 3D virtual tour feature were easier to remember.
Overall better experience	Overall, listings with the 3D virtual tour feature provided a better experience.

Table 4: Each unique identifier(left-side) with its corresponding statement (right-side). The "X" can be replaced by either feature - "2D image" or "3D virtual tour".

Feedback questions
Did you encounter any challenges or limitations in imagining yourself living in the apartments based solely on 2D images?
Did you encounter any challenges or limitations in imagining yourself living in the apartments based solely on 3D virtual tours?
Were there any areas or aspects of the apartments that you wished were better captured or showcased in 2D images?
Were there any areas or aspects of the apartments that you wished were better captured or showcased in 3D virtual tours?
Did you encounter any areas where the survey fell short or where there may have been a misunderstanding?

Table 5: Feedback questions from the survey

C EASE OF USE AND USEFULNESS RESULTS

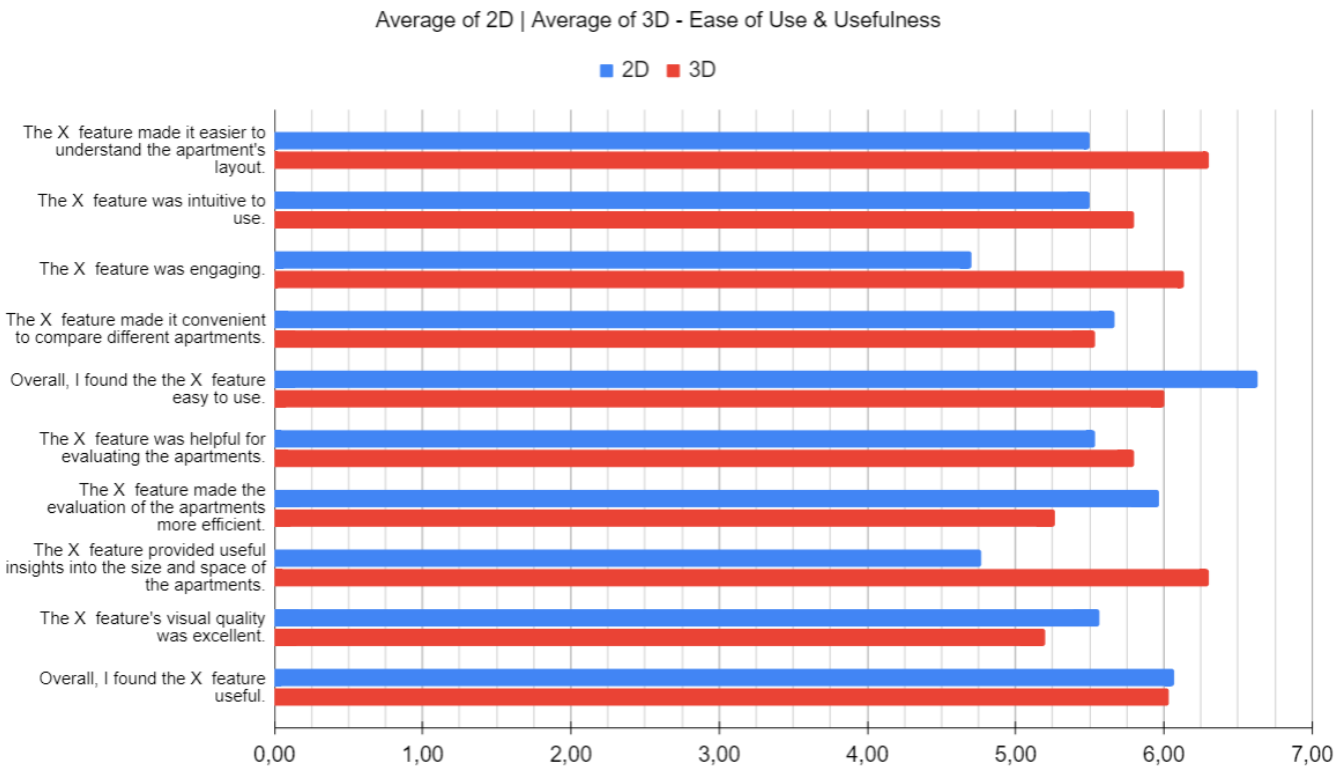

Figure 5: Average scores for each Ease of use and Usefulness for both 2D and 3D.

D PLATFORM STATEMENT RESULTS

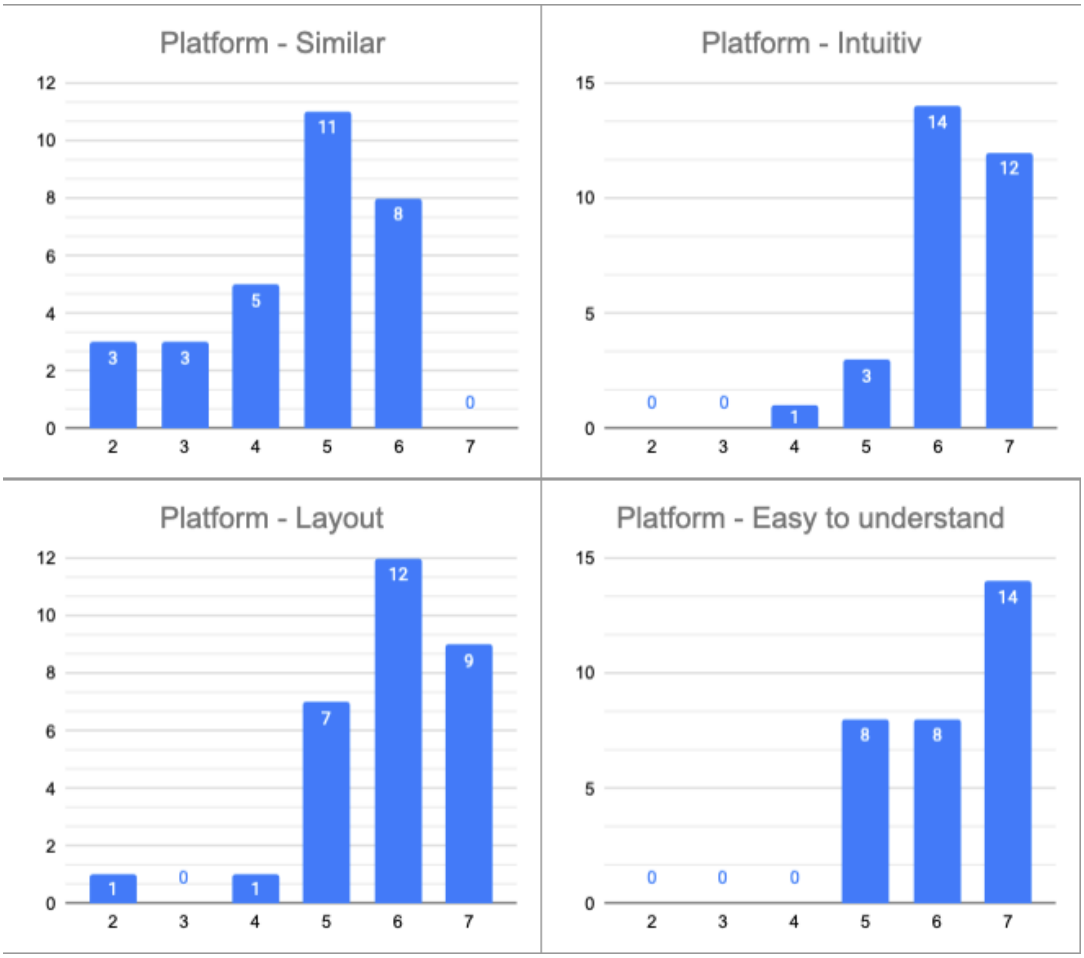

Figure 6: Histograms of the platform statement scores.

E COMPARISON STATEMENTS RESULTS

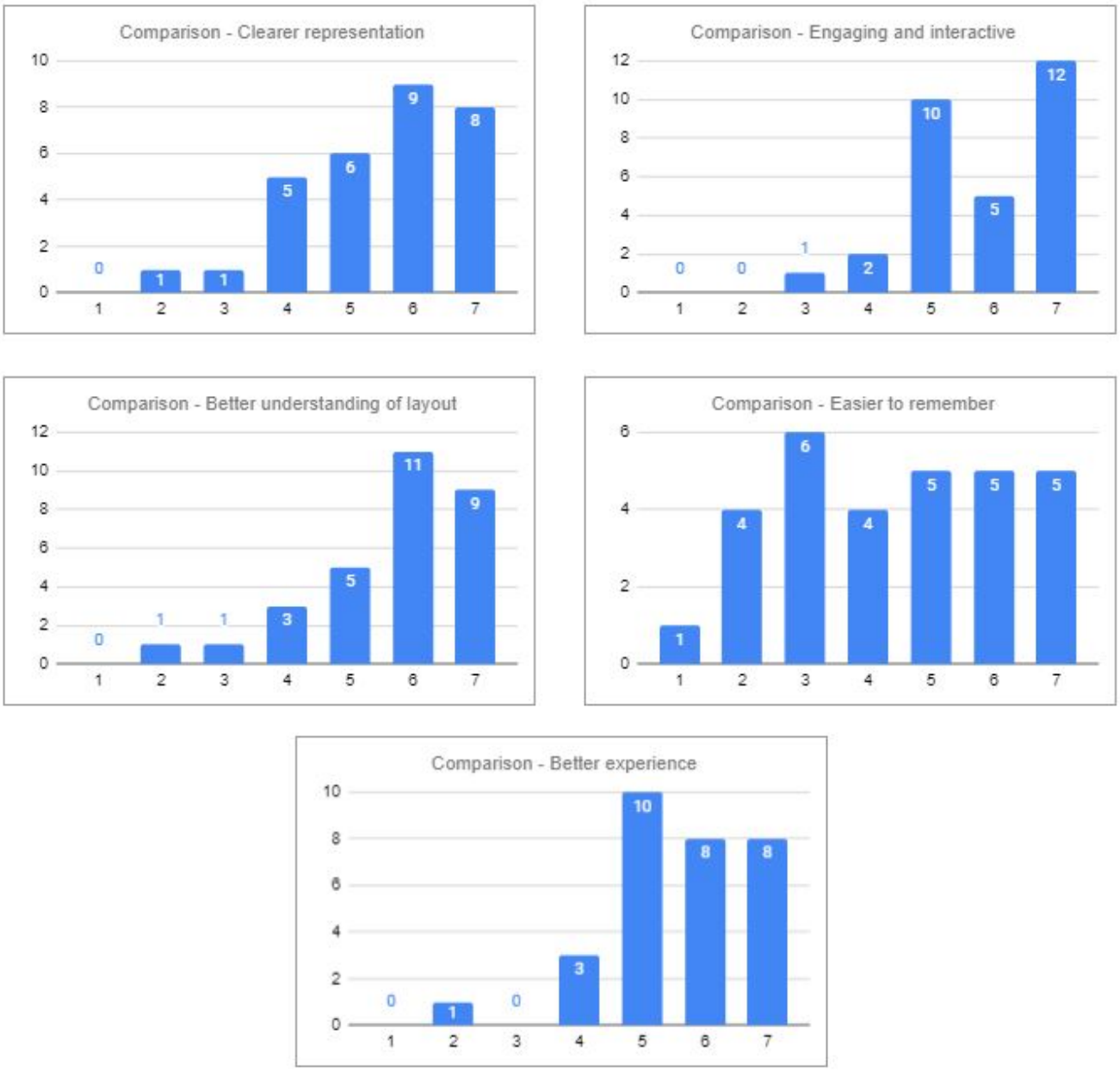

Figure 7: Histogram for each score on each comparison statement.

F FEEDBACK QUALITATIVE CODING

Did you encounter any challenges or limitations in imagining yourself living in the apartments based solely on 2D images?

Participant nr.	Feedback	Code	Score (2D / 3D)
1	It was difficult to get an understanding of how each room fitted together with the others.	Layout	5 / 7
14	Without a floor plan its hard to grasp the layout of the apartment.	Layout	2 / 7
8	no	No	
10	no	No	
12	No	No	
24	No, not with the situation plan as a part of the layout	No	
25	Nej	No	
27	No, i think the 2D pictures were good and showed the apartments well.	No	
28	no	No	
2	Sometimes it limits the feeling of how it would be living in it.	Overall - Usefulness	6 / 7
15	Many of the appartments where in tottaly white colors wich made it look like a hospital or other clinical departssments which wasen't idealy	Quality	2 / 3
3	Sometimes the space in the room can be hard to determine solely from 2D images.	Size&Space	4 / 7
4	Yes, it was quite hard to imagine how small or big the induvidual room was, even though you had furniture for comparison.	Size&Space	4 / 7
7	sometimes it's unclear how the dimentions really are from pictures	Size&Space	4 / 7
9	hard to imagine different furniture in the apartments	Size&Space	4 / 6
17	I think the limitation was evaluating the space aquired with each appartment. The samller appartment felt as spaciuos as the bigger ones.	Size&Space	3 / 7
19	Det er lidt svært at vurdere størrelser ud fra 2d tegninger	Size&Space	6 / 6
20	I had an easier time getting an idea of scale, in the aparments featuring the 3d feature	Size&Space	4 / 7
22	It was difficult to get an intuitive understanding of the size of the ampartment and the different rooms. This is also why i like to see the appartments in real life and not only judge the layout on images.	Size&Space	2 / 7
23	Some space limits yes	Size&Space	6 / 7

Figure 8: Coding of the answers to the first feedback question.

Did you encounter any challenges or limitations in imagining yourself living in the apartments based solely on 3D virtual tours?

Participant nr.	Feedback	Code	Score (2D / 3D)
2	Would be nice to move around.	Intuitive	6 / 7
10	man kan ikke bruge piltaster	Intuitive	7 / 2
20	I would have liked an overlay or the likes that told me the controls. If i wasnt told i could move around with WASD, i would most likely only move around with the buttoms on the left side	Intuitive	7 / 5
1	Not really	No	
7	no really	No	
9	not really	No	
15	no	No	
19	nej.	No	
22	No	No	
24	No	No	
28	no	No	
11	Jeg ville foretrække 2d billeder, og 3d er "bonus"	Other	
12	The 3D tour was a good suplement, but the 2D images are essential, especially the floorplan	Other	
3	When you click a new room, the the view could make a wierd turn.	Overall - Ease of use	7 / 7
25	Ikke rigtigt, måske at når man trykker og trækker for at kigge rundt, så var det lidt langsomt. Måske fordi jeg er normalt har en mus med højere dpi	Overall - Ease of use	6 / 6
17	The only limitation is how to activate the 3D virtual tour. I felt it's uneccesery to choose the option and click again to activate it, instead of just choosing it and be sat in the virtual tour directly	Platform - Layout	5
8	a little lag in apartment 8	Quality	4 / 4
4	It was quite hard to get an overview of the buildning and see the bigger picture and the next rooms while in. It felt like I was a bit too close to everything.	Size&Space	4 / 7
14	Other than some of the apartments were small and ugly in comparison to the non 3D, no, getting a realistic representation of the apartment was easier	Size&Space	4 / 7
27	I personally dont think that the 3D virtual tours gave a better view than the 2D pictures, allthough the size of the apartments were better shown in 3D.	Size&Space	6 / 7
23	yes	Yes	

Figure 9: Coding of the answers to the second feedback question.

Were there any areas or aspects of the apartments that you wished were better captured or showcased in 2D images?

Participant nr.	Feedback	Code	Score (2D / 3D)
14	Floor plan	Layout	2 / 7
20	I had a hard time figuring out where the different doors where located in the 2d images, mostly in the floorplan, but also in some of the other pictures	Layout	6 / 7
2	Not really, the confusion of which room youre in, is getting solve by the overview image.	No	
7	no	No	
15	not in particular	No	
23	no	No	
24	No, it was fine	No	
25	Ikke rigtigt	No	
27	Not any soecific things	No	
28	no	No	
10	køkkener	Other	
1	Location of the apartment	Overall - Usefulness	5 / 7
12	It´s a detail, but I would prefer if the floorplan was the first image to create an overview before diving into the other pictures	Platform - Layout	7
3	The other services such as nybolig, provided an image of the apartment from the outside. Which shows a bit of how the neighbourhood looks like.	Platform - Similar	5
8	the 3D image is a bit funny	Quailty	4 / 4
17	The background looking out of the windows and balconies, instead of it being blurry.	Quality	6 / 4
4	Maybe measurements	Size&Space	4 / 7
6	A more overall image of the big rooms, so you can see more	Size&Space	5 / 6
19	størrelserne på møblerne i relation til hinanden og tykkelsen på væggene	Size&Space	6 / 6
22	The relative room and space size, fx how much space the couch actually takes up.	Size&Space	2 / 7
26	some kind of numbers on the plan drawing like in meters so you can understand the size more	Size&Space	3 / 7

Figure 10: Coding of the answers to the third feedback question.

Were there any areas or aspects of the apartments that you wished were better captured or showcased in 3D virtual tours?

Participant nr.	Feedback	Code	Score (2D / 3D)
26	the controls for the virtual tours. i had an easy time but i don't think everyone knows how to move around in a program like this if they don't know the controls and havent played video games or stuff like that	Intuitive	7 / 7
28	could be nice if the walking pace was a bit faster, to slow	Intuitive	6 / 6
3	Not that i can think of.	No	
10	no	No	
14	Im not sure	No	
15	no	No	
19	nej.	No	
23	no	No	
25	Ikke rigtigt	No	
27	No :)	No	
12	Not really, but it could be a little confusing sometimes - maybe if the view was from an angle higher up	Overall - Ease of use	7 / 5
2	It covers most of the departments. In Apartment 4 it would be great to see the whole bathroom, like showing the shower head. The bathroom have a corner which makes it difficult to cover for such a small room.	Overall - Usefulness	6 / 7
22	It would also be nice if you could use a zoom feature and "raise" the camera above the appartment to get a larger view of the appartment rooms.	Overall - Usefulness	4 / 7
5	a zoom feature maybe, or some guidance in navigation	Overall - Usefulness Intuitive	6 / 7 7 / 6
4	An overview of the buling	Platform - Layout	7
20	I would have liked more buttoms on the left side.	Platform - Layout	7
24	Maybe full 360 overview	Platform - Layout	6
1	Not really. Other than outside environments	Quality	5 / 6
7	missing toilet paper in some of the apartments	Quality	5 / 6
17	like in 2d, a more interactive background going outside in balconies and looking through windows can make a big difference in the interaction happening	Quality	6 / 4

Figure 11: Coding of the answers to the forth feedback question.

Did you encounter any areas where the survey fell short or where there may have been a misunderstanding?

Participant nr.	Feedback	Code	Score (2D / 3D)
1	No	No	
2	No. Overall it is very complete. I really like the ideas of 3D images.	No	
3	I dont think so	No	
7	no, it was very noice	No	
11	no	No	
12	No	No	
14	no	No	
17	The survey fullfill its porpuse from my point of view	No	
19	Nej	No	
22	no	No	
23	no	No	
24	No	No	
27	No, it works find and gave me the information i needed about the appartments.	No	
28	no	No	
4	The meaning of the word engaging	Other	
9	technical experience of the website Bugs etc.	Other	
30	En dansk version a spørgeskemaet kunne være rar	Other	
6	Det var forvirrende, at der på forsiden stod "vores lejligheder" og et andet sted på forsiden stod "se lejligheder" :)	Platform - Intuitive	6
15	the interior of the apartments and more color in the rooms. they looked a little bland when the see them beside each other except apartment 1	Quality	2 / 3

Figure 12: Coding of the answers to the fifth feedback question.