VR Virtual Prototyping Application for Airplane Cockpit: A Human-centred Design Validation

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Abstract: The present study aimed to assess how professionals from the aviation industry perceived the usability of an application aimed at developing prototypes of airplane cockpits, in virtual reality, from a human-centred design perspective. 12 participants from the aeronautical industry took part in the study. An evaluation using the SUS (System Usability Scale) resulted in a final score of 81.3, while the results from the SAM (Self-Assessment Manikin) indicated a neutral-positive trend towards the application. From participant's observations and comments, the application's potential to improve airline security, pilot comfort, and cockpit design efforts, was recognized and appreciated. Despite the positive interactions, some aspects of the application were found to need further improvement, to better align with the expectations and needs of the professionals towards which the application is being geared to.

1 INTRODUCTION

For companies to find success in the current commercial market climate, they must plan, develop, test, and release iterations and improvements to their various products in increasingly shorter time spans (Ottosson, 2002). To alleviate the risks associated with product design, many companies now opt to first create Virtual Prototypes (VP), leaving the production of physical, Real Prototypes (RP) to the later stages of development, to keep costs down (Choi & Cheung, 2008).

When working with VPs, typically CAD applications are used to create digital mock-ups and 3D models of designs that should be as realistic as possible given the available technology. While these VPs can be worked with using a standard PC monitor, they are even more advantageous when used alongside a virtual reality (VR) system, as this gives users a better sense of how the product will look in the final, physical product. Professionals can thus more easily detect errors or areas that can be improved (de Sá & Praun von, 1998, as cited in de Sá & Rix, 2000, p. 130; Wolfartsberger, 2019). In recent years, the technology of various VR systems has rapidly improved, giving consumers access to high quality VR experiences, while decreasing the amount of setup required, as well as the negative effects that come from using it, at a relatively low cost (Gerschütz et al., 2019).

However, despite the advantages of interacting with a VP using a VR system, in general, it has not yet been established how to optimize the design all interactions that might occur between users and a VR environment. This issue is made even more complex when taking into consideration the various interaction modalities that a system might use, the level of familiarity that users have towards being and working in a VR environment, and the various potential uses for VR applications (Berni & Borgianni, 2020; Wolfartsberger, 2019).

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VR for Cockpit Design

According to statistical data regarding air traffic accidents with more than 2 deaths, involving aircrafts transporting more than 19 passengers, between January 1st, 1950, and June 30th, 2019, 49% of all accidents occurred due to pilot error, which may be categorized as Improper procedure, Navigation error, and Spatial disorientation, among others. If the range is restricted to the 2010s, this number increases to 57% (Statistics, 2022). In their study regarding pilot checklists, Degani and Wiener (1993) correlated human factors issues with aviation security. This data corroborates how important a good cockpit's design is, as it enhances the ability of pilots to make decisions more efficiently, safely, and quickly. Zaitseva and Dubovitskiy (2020), in turn, assessed how the rigour of a cockpit's structuring and signalization, as well as the importance and rationalization of the worker's workspace, affects their efficiency and functional reliability, identifying these as factors that can prevent a plethora of human errors.

When designing an application to be used in a professional setting, such as one to work with VP, it is important to appropriately design and set up how interactions will occur. It should be ensured that whichever interactions that are designed are easy to use and increase the application's acceptability (Nielsen, 1993). These interactions will be influence various aspects of the application, such as its intuitiveness and how satisfied users feel with it (Nielsen and Molich, 1990).

A human-centred design approach looks to attend to the user's needs (Keinonen, 2008), and to create more intuitive designs (Giacomin, 2014). According to ISO 9241-210 (2019), a human-centred design approach carries great benefits, both economic and social, to all those involved, such as decreasing the risk of product failure, improving the product's quality, and avoiding the chance of harm occurring due to its use.

This study aims to evaluate how a virtual reality application, intended to aid in virtual prototyping airplane cockpits, performs in terms of usability, from a human-centred design approach, among users from the aviation industry. Fundamentally it seeks to answer the following question: How is the usability of a virtual reality cockpit prototyping application perceived by users from the aviation industry?

2 RESEARCH METHODOLOGY

The experimental procedure for this study, presented below, was split into three steps: (1) Signing the informed consent form; (2) Using the VR application; (3) Answering the final questionnaires on the tablet device.

Participants

12 participants (8 male), between 18 to 56 years-old (M = 39.25 ± SD 12.10) participated in the study. Three participants were left-handed, and eight participants reported having no visual issues. All participants worked in the aviation industry, albeit in different areas, such as piloting, project management in maintenance, repair, and operations (MRO), intelligence, aeronautics engineering, airship maintenance and modification, cabin crew, among others. In general, participants reported having a slight amount of previous experience with VR, and moderate experience with playing video and mobile games. Only three participants had never previously used VR.

VR Application

A VR headset HTC Vive Pro was used to interact with the application. This system was composed of a Vive Pro headset, 1 Vive Pro controller (held on the right hand), and 2 Vive base stations 1.0 (HTC Corporation, n.d.). A tablet device was used to fill out the questionnaires.

The VR application was created with the aim of aiding airline industry professionals with creating, modifying, and validating an airplane cockpit's instrument panel, giving them the freedom to manipulate instruments on a VP.

The system requirements and specifications were developed alongside users, with task goals and specifications being identified according their necessities. When starting the application, in its current stage, the virtual environment is composed of the inside of a Falcon 50's cockpit, in which an empty instrument panel, with a main and a secondary section, can be found. Above the main section, users can find the "Gallery". This gallery has two states, "Closed" (Figure 1, Left) and "Opened". When opened, users can find inside it a list of instruments with which they can interact. The size of these instruments, while in the gallery, is scaled down, and they are scaled back to their actual size when moved outside the gallery and into the virtual panel. When the instruments are placed on the panel, users can do various actions with them, such as: manipulating the location of instruments; creating groups of instruments to manipulate their location in tandem (groups of two or more instruments); switching the location of two instruments with each other; aligning the position of instruments with another's; and placing instruments against each other. To do these actions, users can perform three interactions through the Vive Pro controller: “touch”, “grab”, and “select”. To “touch” an object or icon, users must pass one of their intermediary fingers of the virtual hand (that is, index, middle, or ring fingers) through the object or icon they want to touch, without pressing any of the controller’s buttons. To “grab” an object, in turn, users must press the controller’s Trigger Button while the virtual hand is in contact with an object with a yellow outline (Figure 1, Right), which indicates which object will be grabbed. Lastly, to “select” an object, users must press the button at the centre of the controller’s touchpad while the virtual hand is in contact with an object with a yellow outline, which indicates which object will be selected.

To place an instrument on the panel, users must first open the “Gallery” by touching its icon. Afterwards, they can “grab” the instrument from the gallery, and move it to the intended location on the panel. Once there, pushing the instrument towards the panel will cause it to “snap” into place, and users can let go of it (Figure 1, Right). By grabbing the instrument again, users can move it somewhere else as well.

While positioning an instrument on the panel, if other objects have already been placed on it, position aid guidelines will appear between the centre of the grabbed object and the centre of nearest object whose centre is in the same vertical (when objects are side by side) or horizontal (when an object is above the other) axis. These guidelines facilitate the process of organizing instruments in relation to one another. Additionally, while placing objects next to each other, users are aided by a “snapping” function, which brings the grabbed object near another object already on the panel, leaving a pre-defined amount of space between them.

When placing objects, the application also detects and signals when objects are overlapping one another, when part of an object is placed outside the panel’s bounds (Figure 2, Left), or when part of an object is overlapping the cockpits side walls.

Lastly, the “select” interaction can be used to either group 2 or more objects together and move them all at once, or to switch the location of an instrument with that of another. To create a group, users must individually select each object that will be part of that group, by using the “select” interaction on each one. When an object is selected, it is marked with a green icon (Figure 2, Right). The action of switching the location of two objects with each other can only be done between objects with an equivalent size. To do this action, users must first select both objects, using the “select” interaction, and then “touch” the “Switch” icon that will be available on the environment. While this action has been implemented, it was not used in this study.

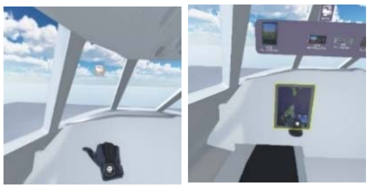

Figure 1: Gallery – Closed (Left). Instrument placed on the panel, with the yellow outline around an instrument (Right).

Figure 2: Object outsider the panel’s bounds (Left), Group with two instruments selected (Right).

This VR application was updated after an initial usability study (Silva et al., 2023). In comparison to that version, changes to actions and interactions were implemented in the current version based on the feedback gathered through said study. The following is a list of the main changes. (1) The functionality of the “gallery” was changed, with users now being able to grab instruments directly from it and moving them over to the panel. Additionally, instruments could be returned to it by letting them go while they weren’t place on the panel (2) The actions required for the “select” interaction were changed, with users now having to first be touching the instrument before pressing the centre touchpad button, and no longer have to keep it pressed.

Procedure

This study was conducted in an aviation event that occurred in October 2022, in Portugal. The study was conducted at one of the event’s booths, where professionals working on the aviation industry were invited to participate. The idea of conducting this study during this event arose in response to the difficulties the researchers had in getting access to users from this industry, due to the schedule limitations of many of these professionals to participate in user-studies.

Firstly, the intended aim of the application’s final version, and at which stage of development it was at the time, were explained to participants. It was also explained that an initial study had already been conducted with subjects not part of the aviation industry, in a decontextualized environment, and the importance of gathering data from professionals in the industry (Silva et al., 2023).

Participants were taken to a private space where they could freely try out the application. A brief explanation about the controller's buttons and their usage was given before they entered the VR environment. Throughout the session, a researcher was available to answer any questions or doubts, while another researcher noted down any observations made by participants. After exiting the VR environment, participants were asked to fill out a set of questionnaires on the tablet device, which were meant to gather demographic information, as well their perception of the application's user experience. These questionnaires were: (1) A Sociodemographic characteristics questionnaire; (2) The SUS (Brooke, 1996), used to measure the participant's perception of usability, and which was also used to compare with the results from the previous study, which also used this tool (Silva et al., 2023); and the (3) SAM (Bradley & Lang, 1994), a non-verbal pictographic scale used to assess the affective reaction of participants regarding the system, separating it into three dimensions (pleasure, arousal, and dominance). A signed consent form was obtained from all participants.

Data Analysis

SUS' data analysis was carried out like in the previous study (Silva et al., 2023), that is, according to the calculations and parameters presented by Brooke (1996), as well as the parameters presented by Bangor et al. (2009). A stratified analysis of SUS, according to the Nielsen (1993)'s scale was also performed. Therefore, results were split into satisfaction, ease of memorization, ease of learning, efficiency and minimization of errors, based on Boucinha and Tarouco (2013).

The median was used as a measure for the analysis of SAM's results. While the mean is more frequently used (Aguirre, 2016), since SAM uses a bipolar scale, Belfiore (2015) suggests that the median should be used instead. The author claims that, since the numbers are connected to a classification scale, using the mean might result in an unintended bias, as participants analyse the scale's label instead of its number. The SAM's median was worked with and justified in the work of Ribeiro (2020).

The results from observing participants throughout the sessions, which were noted down by a researcher, were also analysed.

Data Comparison

This research was carried out as a complement to a previously conducted study in which we aimed to assess the user experience and, among other factors, the usability of the application with an emphasis on the "touch", "grab", and "select" interactions (Silva et al., 2023). The SUS was implemental in the experimental protocol of both studies, and the results obtained were compared to see if any changes to the perception of usability occurred.

Furthermore, special attention was given to participant's comments and observations related to the application's system which were modified from the previous study, namely: the modification to the instrument's gallery; the changes to the "select" interaction; and how to add instruments to a group.

3 RESULTS AND DISCUSSION

SUS

The SUS had a final score of 81.3, which corresponds to a classification of "acceptable", according to Brooke (1996) and Bangor et al. (2009). In Bangor et al. (2009)'s adjective perspective, SUS, in general, is considered as being "Good".

Figure 3 shows each participant's SUS results, with the orange bars indicating female participants, and blue bars indicating male participants. Bangor et al. (2009)'s acceptability (green line) and non-acceptability (red line) limits, as well as the overall mean (purple line) are also shown. It can be noted that, of the 5 lowest scores, 4 came from the female participants, while the other came from a male participant who worked in airplane manufacturing. It can also be noted that the 3 participants who reported having myopia (identified by a bold outline in Figure 3) were part of the group of lowest scorers (1 female with a score of 72.5, 1 male and 1 female with a score of 70). Left-handed participants gave the two lowest scores (1 male and one female with a score of 70), as well as the highest score (1 male, with a score of 100), all aged between 41 and 49 years old.

Participants that reported having plenty or moderate contact with VR, video games, and mobile games, evaluated the application with a lower mean score of 76. As for participants that reported having had little to no prior contact with VR, videogames, or mobile games, rated the application in a positive way, with a mean score of 87.

Regarding the stratified analysis according to Nielsen (1993)'s scale, it can be noted that all dimensions are above the acceptable level (Figure 4).

Comparing them amongst each other, "satisfaction" and "ease of learning" where the lowest ones, in order. Thus, it can be concluded that the usability parameter, measured using the SUS, was positive.

SAM

Analysing the results from SAM, a trend of neutral-positive affective reaction regarding the application can be noted. In the dimension of "pleasure" (Figure 5, A), the median is at a value right before the extremely positive, which corresponds to a pleasurable reaction. In the dimension of "arousal", the created affection was neutral (Figure 5, B). As for the dimension of "dominance", an affective reaction of positive control was found (Figure 5, C), which demonstrates a feeling of control towards the application.

Regarding profile analysis, no differences were noted between left-handed and right-handed participants. On the other hand, differences were noted between the affective reaction of males vs. females, and between those with previous experience with VR, video games, and mobile games, versus those without (Figure 6). Comparing the results obtained from both sexes, while positive pleasure results were obtained from both, women seem to have had a slightly lower activation. Regarding arousal, the difference in results from both sexes is more significant, as men had a moderate-positive affective reaction, while women had a neutral-moderate negative reaction. As for dominance, men had a bigger perception of a feeling of control.

Looking at data from the perspective of previous experience with VR, videogames, and mobile games, a more positive trend could be noted on those without prior experience. Those without prior experience had a maximum positive affective reaction in the dimension of dominance, while those with prior experience scored two points lower. Regarding the dimension of arousal, a two-point difference was also found, with those with prior experience reporting a neutral affective reaction, while those without reported a moderate-positive affective reaction. Lastly, in the dimension of "pleasure", both groups had the same result.

Observation

During the participant's interactions with the VR application, the following positive aspects were noted: (1) The instructions provided to participants were easily understood; (2) Opening the gallery caused a pleasant surprise reaction, since instruments would poop into view; (3) Participants immediately wanted to grab the instruments found in the gallery; (4) The yellow outline around objects was useful to help understand their 3D dimensions; (5) All participants quickly put the "grab" interaction to use, and easily understood how it worked; (6) Moving an instrument after grabbing it was reported as being fluid and quick; (7) Participants reported that placing the instruments on the panel was intuitive, and they did this action without any issues; (8) Participants quickly perceived when objects overlaid each other on the panel, due to the change of the object's colour; (9) Returning instruments to the gallery was conducted intuitively; (10) Releasing the grab on an instrument, while it was neither in the gallery nor on the panel, caused some surprise, as it would automatically return to the gallery.

Likewise, the following negative aspects were also noted: (1) Participants reported that the gallery could be more visible; (2) Participants had trouble understanding that the yellow outline indicated that an object could be interacted with; (3) Participants reported that the yellow outline was visually confusing; (4) Placing an instrument on the panel's borders raised questions that had to be addressed through the session; (5) Some participants reported that they felt that the indication that an object was being "grabbed" was strange.

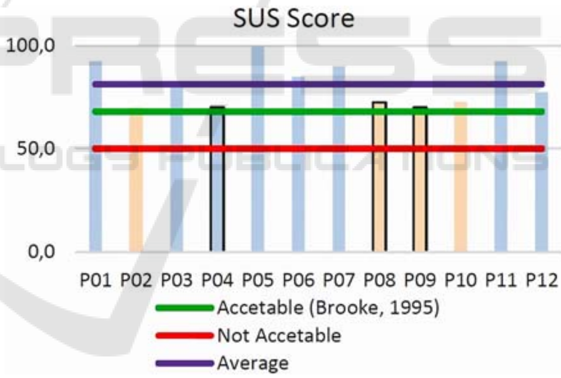

Figure 3: SUS Score.

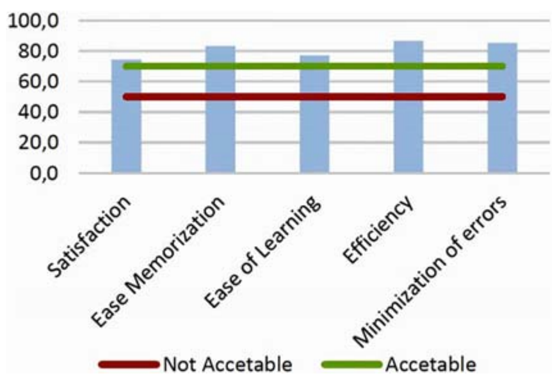

Figure 4: SUS Score – Stratification.

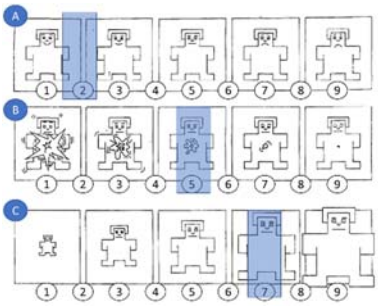

Figure 5: SAM - Pleasure (A), Arousal (B), Dominance (C).

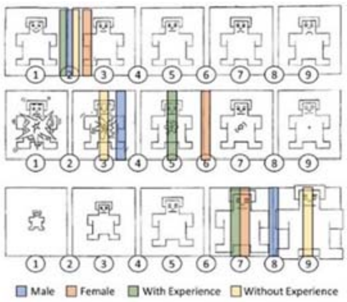

Figure 6: SAM – By profile (male, female, with and without previous experience with VR).

Regarding more general comments towards the application, an aircraft maintenance and modifications engineer reported been pleased with it. Two participants (the MROs), in turn, praised the application, one of them mentioning that he could foresee a lot of potential for it, both for design and assembly of cockpits, from a maintenance and engineering standpoint, as well as for the validation of the cockpit by pilots. One pilot stated that "I hope you'll keep developing this app so that pilots can have more comfort." Another pilot commented that, besides the gains in comfort, using the application could help reduce the number of errors that occur and, potentially, prevent air traffic accidents.

Overall, it could be noted that the application was easy to interact with, from a functionality, usability, and intuitiveness standpoint. However, some aspects regarding visibility and interaction still need to be improved.

Comparison with the Previous Study

In the previously conducted study (Silva et al., 2023), although the VR environment was uncharacterized, and sessions were conducted with a pre-defined sequence of tasks to be carried out, issues were found. Amongst these, we point out: (1) the way in which the "select" interaction was established; and (2) the action of loading instruments onto the slots followed by then dragging them onto the panel. These aspects were changed and tested in the current study. Comparing the two studies, the SUS scores from the previous study had a mean of 68.5, while, in the current study, they have a mean of 81.3. According to Bangor et al. (2009), this means they moved from the marginally acceptable area, with the adjective of "ok", to the acceptability area, with the adjective of "good."

Another change that was noted was in the data stratification, where all dimensions improved, with "satisfaction" and "ease of learning" going from marginal to acceptable.

In the face of these changes, it is clear that the system became more intuitive, functional, and fluid, compared to the version used on the previous study. Additionally, the new gallery was well accepted by participants of this study, although it can still be improved further.

Discussion

From the viewpoint of the VR application's usability, and the experience it provided users with, the application was well accepted and regarded as having a good usability. This includes the easiness of using it, its efficiency, satisfaction, intuitiveness, agility, and dominance. These aspects converge to Nielsen (1993)'s and Nielsen and Molich (1990)'s view of good usability, as well as to ISO 9241-210 (2019)'s metrics of effectiveness, efficiency, and satisfaction. Furthermore, taking these norms into account, this study looked to take a human-centred approach when designing the application, keeping the intended users of its final version in mind.

Some basic aspects of the application, which can be improved further, were also noted, such as the observations raised regarding the gallery, the object's outline, and a neutral arousal response. Nonetheless, when comparing the results from this research with those obtained in the previously conducted study, an improvement of its usability can be noted. As for the application itself and the ideia behind its development, the feedback received was positive, as users noted the potential it has.

This study was faced with some limitations. Firstly, the researchers had trouble contacting users that are part of the application's intended user group, and, as the study was carried out during an aviation event, it was not the ideal context for a study to be conducted in. Some consideration must thus be made regarding the obtained results. Participants were in a positive context and were enthusiastic when they started their session. Complementary, the SUS and SAM are self-reporting tools that assess a user's experience. Therefore, it's possible that the environment in which the study was conducted might have had a positive influence in the user's satisfaction and perception. This aspect is reinforced by Seo et al. (2014) who looked at cognitive-emotional behaviour, and reported that a user's usability perception might be positively correlated with their emotional engagement. To try and address these issues, while recruiting participants, fluence in the user's satisfaction and perception. This aspect is reinforced by Seo et al. (2014)'s study, where the author the importance of criticising the application freely and voicing their opinions, given that the application was still in development.

Secondly, participants had the freedom to do as they pleased while in the virtual environment, as there were no pre-established tasks they had to perform. The result was that not all participants made use of the grouping action (using the "select" interaction). On one hand, this format was useful to see how intuitive the application was and how excited participants were. On the other hand, some areas we wished to assess received less attention than others, which reinforces the need for future research, with a more matured version of the application, following a more structured protocol. Nonetheless, given that this study's protocol was simple and had few functions for users to use, the positive "Freedom" aspect was highlighted.

In continuation of the previous point, the application was still limited in the number of instruments available and actions that could be performed. This might influence the application's usability and the environment's aesthetic.

In future work, we aim to implement the suggestions for improvements that were gathered in this study. We also intend to test and test the more mature version of the application again, in a controlled environment and with a well-established experimental protocol, with participants that are part of the application's intended user group. Another factor that may be important to analyse in future research is the connection between human-centred design and business strategy (Giacomin, 2014). As efficiency and safety can be related with cockpit design, it may be possible to extrapolate a relation between the improvements granted by a VR prototyping tool and effective economic return.

4 CONCLUSIONS

By making efforts to acquire feedback regarding the application's development from professionals in the aviation industry, we aimed to ultimately help promote the application's adoption upon release, as the final version will be geared towards the expectations and needs of these users, specifically those involved with the process of cockpit development and maintenance. While some design changes had previously been implemented in the application, with the intent of improving its usability and the experience it provides users, these came from data gathered next to users who were not professionals in the aviation industry (Silva et al., 2023). While these contributions are still valuable at earlier stages of development, it is paramount to gather the opinions of the intended userbase as early as possible, so they can better shape the application's development. This includes aeronautical designers, developers, engineers, and pilots, for example.

However, as these professionals are not always available to test out earlier developmental builds, opportunities where user data can be gathered quickly and efficiently, such as industry events, must be taken advantage of. Importantly, such events also serve to show not only the usefulness of a virtual prototyping application, but also the usefulness of having such an application working in virtual reality, thanks to the hardware that is currently available, and the contributions users can have in shaping the development of applications they might use in the future.

Taking the results from this study into account, other functionalities and interactions of the application can still be developed further, and more rigorous testing with these professionals must be conducted. However, these future tests must be conducted in a structured environment and with controlled tasks, to fully assess the participants' opinions and potential issues of the application during use, not only regarding the interactions and actions that are currently available on it, but also regarding those actions and interactions which are planned to be implemented by the final version.

Throughout each session, it could be noted that the professionals from the aviation industry were pleased with the direction towards which the virtual reality cockpit prototyping application was being developed. As four participants noted, the aim is for this application, when finalized, to be a tool that can help promote the safety and well-being of all those inside an aircraft, starting with pilots themselves, by improving the cockpits with which they work with.

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REFERENCES

Aguirre, A. L. R. (2016). Viés de atenção para pistas relacionadas com alimentos saudáveis e não saudáveis entre crianças com diferentes pesos ao nascer. Tese (Doutorado em Psicologia). Porto Alegre, Universidade Federal do Rio Grande do Sul, pp. 155.

Bangor, A., Kortum, P., & Miller, J. (2009). Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *Journal of Usability Studies*, 4(3), pp. 114-123

Belfiore, P. (2015). Estatística aplicada a administração, contabilidade e economia com Excel e SPSS. Rio de Janeiro: Elsevier.

Berni, A., & Borgianni, Y. (2020). Applications of Virtual Reality in Engineering and Product Design: Why, What, How, When and Where. *Electronics*, *9*(7), 1064.

Boucinha, R. M., & Tarouco, L. M. R. (2013). Avaliação de Ambiente Virtual de Aprendizagem com o uso do SUS - System Usability Scale. *RENOTE*, 11(3), 1-10.

Bradley, M. M., & Lang, P. J. (1994). Measuring Emotion: The Self-Assessment Manikin And The Semantic Differential. Journal of Behavior Therapy and Experimental Psychiatry, 25(1), 49-59.

Brooke, J. (1996). SUS: A "Quick and Dirty" Usability Scale. In *Usability Evaluation In Industry* (Vol. 189, pp. 207–212). CRC Press.

Choi, S. H., & Cheung, H. H. (2008). A versatile virtual prototyping system for rapid product development. *Computers in Industry*, *59*(5), 477–488.

de Sá, A. G., & Rix, J. (2000). Virtual Prototyping: The Integration of Design and Virtual Reality. In *CAD Tools and Algorithms for Product Design*, 128–150). Springer, Berlin, Heidelberg.

Degani, A., & Wiener, E. L. (1993). Cockpit Checklists: Concepts, Design, and Use. Human Factors, 35(2), 345–359.

Gerschütz, B., Fechter, M., Schleich, B., & Wartzack, S. (2019). A review of requirements and approaches for realistic visual perception in virtual reality. *Proceedings of the International Conference on Engineering Design, ICED*, *2019-Augus*(1), 1893–1902.

Giacomin, J. (2014). *What Is Human Centred Design? The Design Journal, 17(4), 606–623*

HTC Corporation. (n.d.). *VIVE Pro Full Kit*. Retrieved September 13, 2022, from https://www.vive.com/us/product/vive-pro-full-kit/

ISO 9241-210 (2019) Ergonomics of human-system interaction.

Joyce, R., & Robinson, S. K. (2019). Evaluation of a Virtual Reality Environment for Cockpit Design. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63(1), 2328–2332.

Keinonen, T. (2008). User-centered design and fundamental need. In: Nordic Conference on Human-Computer Interaction: building-bridges, 5, Lund: ACM New York, 211-219.

Nielsen, J. (1993) *Usability Engineering*. Academic Press, Inc., Harcourt Brace & Company, San Diego, USA.

Nielsen, J. & Molich, R. (1990). Heuristic evaluation of user interfaces. In: SIGCHI conference on human factors in computing systems. proceedings. ACM.

Ottosson, S. (2002). Virtual reality in the product development process. *Journal of Engineering Design*, *13*(2), 159–172.

Ribeiro, I. M. (2020). Mapeamento da hedonomia e das experiências emocionais: A percepção do aluno no ensino superior sob a perspectiva do design emocional. Tese (Doutorado em Design) Recife, Universidade Federal de Pernambuco pp. 472.

Seo, K.-K., Lee, S., Chung, B. D., & Park, C. (2014). Users' emotional valence, arousal, and engagement based on perceived usability and aesthetics for web sites. International Journal oh Human-Computer Interaction, 31(1), 72-87.

Silva, E., Margolis, I., Nunes, M., Sousa, N., Nunes, E., & Sousa, E. (2023). Analysis of the user experience (UX) of design interactions for a job-related VR application. HUCAPP - 18th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications.

Statistics, Causes of Fatal Accidents by Decade, [online]. (2022). Available from http://planecrashinfo.com/.

Wolfartsberger, J. (2019). Analyzing the potential of Virtual Reality for engineering design review. *Automation in Construction*, *104*, 27–37.

Zaitseva, A. A. & Dubovitskiy, M. A. (2020). Ergonomic of Instrument Panel and Sensors in the Passenger Aircraft Cockpit and its Impact on the Human Factor Manifestation and Flight Safety, *2020 International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)*, 1-4.