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THE USE OF VIRTUAL REALITY TO SUPPORT ENGINEERING DESIGN REVIEWS

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ABSTRACT

With more advanced technology and simulation software becoming available, the idea of incorporating immersive technologies, such as virtual and augmented reality in mechanical design. Specifically, this research seeks to understand the current state of the art use of immersive technologies within the DoD Acquisition Process. First, the state-of-the-art needs is analyzed, so that research can be adequately directed to make this future a reality. Three opportunities are identified 1) use of immersive technology to support design reviews, 2) the use of current technology to support engineering design review tasks, and 3) experiments and formal studies to evaluate the impact of immersive technologies on engineering design review tasks.

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1 INTRODUCTION

Incorporating immersive technology into design reviews to improve decision making is not a new concept, but the existing research on the topic needed to be collected and analyzed before further research could be initiated. This includes investigating each aspect: design reviews, decision making, and immersive technologies.

1.1 Understanding Design Reviews

Design reviews are an integral part of the engineering design process and can occur at all stages within the process. For example, in the design process specified by Pahl and Beitz [1], design reviews can be held in the clarification of task phase to discuss the requirements that a product must fulfill. Design reviews can also be held during the conceptual design phase to discuss initial concepts for the product, or during the detailed design phase, where individual components of the overall product are being selected.

Design reviews are also used as part of acquisition processes, as shown in Figure 1.

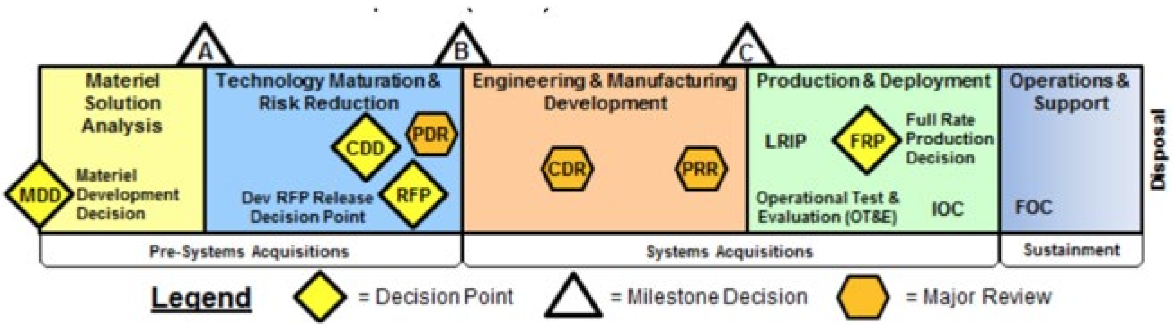

Figure1: US Defense Acquisitions Process.

In these processes, design reviews serve as part of the exit condition between stages; for example, a preliminary design review (PDR) is required to be conducted for the chosen solution to exit the Technology Development Phase of the Department of Defense acquisition process. [2]. Other forms of design reviews are conducted between other stages, such as the tradespace scrum conducted at the end of the user needs and technology opportunity resources stage, or the post-critical design review (CDR), before entry is authorized into the engineering and manufacturing development phase [2].

The term "design review" is common in the mechanical design process, but it does not have a definitively established meaning. Some definitions describe design reviews as meetings that are "important milestones within a product development process" [3] while others provide more detail, explaining that design reviews are meetings during which the team "presents its design choices in detail to an audience of technical professionals who are there to assess the design, raise questions, and offer suggestions" [4]. Other definitions refer to the capability of design reviews to assess design maturity [2]. Within the Department of Defense Acquisition process, there are different milestone design review with specific entrance and exit criteria. Some of the major reviews include:

- Preliminary design review: the preliminary design is evaluated against technical requirements and within cost and scheduling constraints
- Critical design review: the design specifications are reviewed to determine if fabrication, demonstration, and testing can occur within the expectations of the program.
- Production readiness review: the production readiness of the solution is determined without unacceptable risks

Design reviews may occur at major formal milestones or may occur within informal discussion of smaller teams to support the progress of the program. While there is not an agreed upon definition for design review, in this paper we adhere to United States Department of Defense Acquisition process, as primarily meetings where a design is evaluated to approve of its progress in the process [5].

Many activities are conducted during design reviews. These may include briefings on the design problem being addressed, presentations on proposed solutions, including drawing packages or 3D models, and discussion of the overall project [4]. During these discussions, attendees are tasked with making numerous decisions, ranging from the suitability of suggested solutions and test protocols to the inclusion of requirements or approval to move to the next phase of the process. Design evaluation and progression in the design process both require decisions to be made by the stakeholders; thus, design reviews are key decision-making points and stage gates in the design process.

1.2 Decision-Making

Design reviews are arenas for decision making; moreover, the decisions that result are made by and in teams, not just individuals. It therefore is critical to understand the factors that influence team decision-making and performance [6]. Much work has been conducted in the field of team decision-making. These efforts include studies that attempt to develop assessment tools for team decision-making [6–8], and others that worked to understand the interplay between cognitive load and decision-making [9,10].

Other studies sought to understand the various factors that impact the decision-making process. An analysis of multi-criteria decision methods is detailed in [11]. These decision-making methods include multi-attribute utility theory, analytic hierarchy process, and case-based reasoning, among others [11]. In [12], individual satisfaction is explored as a factor contributing to decision-making and team performance and is found to have a paradoxical relationship with the presence of debate in teams. Debates increase the overall team performance but negatively impact individual satisfaction in the moment, as well as overall team performance in the future [12]. The role of management and professional control in decision-making teams was studied in [13]. The presence of management controls within teams was found to reduce role ambiguity and role conflict within teams, thus aiding the decision-making process [13]. Various activity and discourse roles as they impact decision-making were explored in [14], while [15] studied the activities of the process for time-sensitive decision-making, as well as the role of technology.

O'Neill and colleagues [16] examined the decision-making process of face-to-face teams versus virtual teams, meeting over instant messaging, and found that face-to-face teams were faster, more efficient, and considered more information than the virtual teams. This study is of particular interest, especially considering the recent increase in distributed teams and increasing remote work. If virtual teams are going to be a major part of the design review and decision-making process, a key question is related how to overcome the challenges in distributed teaming.?

A potential solution to address challenges with distributed work is to use immersive technology to support virtual teams and their decision-making processes and to increase user perceptions of presence. Immersive technology has many definitions, but in this paper is defined as any technology that allows users to feel like they are in the simulated environment. This includes interventions such as virtual reality, augmented reality, mixed reality, and sufficiently large interactive 2D displays that create a sense of presence in the virtual environment.

Thus, this paper will discuss the current state of the art in immersive technology with a focus on use cases to support design reviews. The major literature findings discussed in Section 2. The gaps and areas for future work identified from the literature are summarized in Section 3, followed by conclusions in Section 4.

2 Virtual Reality

Virtual Environment (VE) or Virtual Reality (VR), used interchangeably, can be defined in simple terms as 'a computer-generated world' [17] that perceptually surrounds the human [18], and makes the human perceive it as real and lets the human interact with it using special human-computer interface equipment [19]. In the last couple of decades, the increase in accessibility and the increase in graphics and computing power has made use of VR technology ubiquitous. To make the VE immersive, the technology uses real-time computer graphics, body tracking technology, and sensory devices such as touch, video, and audio. [20].

The groups of VR systems can be categorized by the level of immersion that they offer. Non-immersive systems are desktop VRs that do not surround the human and create a VE in 2D; semi-immersive systems are improved versions that offer head tracking on a desktop and enhance the feeling of "being there"; and immersive systems let the user completely immerse in the VE and surround the user [19]. Immersive systems such as Head-Mounted Displays (HMD), and Cave Automated Virtual Environments (CAVE), among others, use technology enhanced by audio, video haptic, and other sensory interfaces [19].

The three key features that make VR unique are immersion, presence, and interactivity, and these three pillars play a significant role in VR because they seem to influence the users' perception of it [21]. The concept of immersion is no different than the feeling of being engrossed in a movie, but the person watching a movie would later remember that they were in a theatre, while a person immersed in a virtual environment would later report the sense of having been in that virtual environment [22]. Immersion is the objective level of sensory fidelity provided by a VR system and it is the user's level of engagement with that system [23,24].

Presence, on the other hand, is one's sense of being in the VR system, and is an illusion based on the perception and not on the cognition of the user [24]. Thus, presence is the subjective experience of the user and a psychological response of a user experiencing a VR system [24]. This sense of presence in immersive VR makes it a unique technology. In IVR, it is the illusion of being "there" in a virtual environment. Sense of presence is a perceptual illusion that triggers the brain-body system to react to a perceived signal and is not a cognitive illusion that reacts slowly to a signal and concludes that the body is not in the environment the brain perceives itself to be in [18]. Interestingly, even if the user knows that it is an illusion, the user still responds to this illusion. This subjective experience makes "presence" a unique aspect of virtual reality and a real power of VR, therefore it must be better understood to effectively use VR technology.

The handbook of Virtual reality states that experience of presence is a combination of "Immersion (capacity to immerse in the environment); Interaction (capacity to interact with the environment); and Imagination (capacity of mental imagery)" [25]. This combination of features is the key to enhance the power of VR. Based on the literature reviewed, the significance of imagination is not explored extensively. The variables that define these features are divided into two categories, media characteristics and user characteristics [26]. Media characteristics include display medium, sensory information provided, user's level of control, and ability to change aspects of the environment. Some of the user characteristics are individual variables like age and gender, cultural variables, motor abilities of the user, and motivation. A virtual environment encompassing these variables and the level of significance of these variables will define virtual environment being developed.

2.1 Immersive Technologies in Architecture

In *Collaborative Design in Virtual Environments* [27] VR is evaluated to support for collaborative design, but it is limited to architectural design scenarios. While there are many ideas in the book that cross over into mechanical design, the tools and methods are ultimately different. Architecture focuses on the environment around the user, whereas mechanical design focuses on a specific device within that environment. However, the book was a good resource for background on the psychology of design in a general sense, and some tools within the software discussed would be just as useful in mechanical design. The book shows that architecture already has thriving research into the topic of immersive technology for collaborative design and is a great tool for comparison to the same topic for mechanical design.

In further searches, more papers were found on the topic of interest in the context of architecture outside of the book described in the previous paragraph. Rosenman et al. [28] discuss a framework for multi-disciplinary design reviews. They believe that virtual environments are necessary for immediate communication of ideas and design changes among the different disciplines. For example, plumbers can describe a change they want to make to the building design and immediately communicate that to the architects, engineers, electricians, and other tradespeople involved with the project. They also describe the ability to view different parts of the same virtual model within the virtual world by stripping away other features to just show part of the design like using tracing paper to add the different subsystems. Both ideas can apply to and be incorporated into mechanical design as well. There are some qualitative results in [29] of a different architectural design review of an office space by Chan. Chan found that the immersive visualizations helped the participants form more holistic opinions about the office.

Maher, Bilda, and Gul [30] conducted an experiment on three pairs of architects designing with different tools: paper and pencil, a digital smart board, and a virtual world application (3D environment represented on a 2D screen). They found hard data that suggests that the tools presented to the designers affected how they created solutions. Due to the effort it takes to recreate a drawing on paper, the designers did not spend much time altering ideas with pencil and paper but spent more time relatively creating alternative ideas. The digital tools, in contrast, allowed for easier alteration which led to fewer alternatives being created and more time spent on accurately modeling an idea. The research implies that adding more advanced tools too early in the design process could hinder creativity. This same conclusion is shown in [31] which used immersive technologies in an architectural design problem. This time, the technologies are CAVE systems which provide a greater sense of presence than the systems used in [30]. This experiment was smaller with only two architects designing a floor plan, but they had different levels of experience. Both were found to be less willing to investigate alternative solutions and to focus more on fine-tuning their solutions to look as good as possible. An important advantage to designing in virtual reality found in [30] was that it allowed for instant feedback on functionality of the floor plan with the participants constantly virtually walking through to gauge comfort.

Leigh et al in [31] discuss the software and hardware developed for architectural design and not the results of the technology, besides the fact that the users liked it. Additionally, since [31] is from 1996, much of the hardware and software detailed within it predates the recent leaps in technological advancements.

The most relevant study to mechanical design is [32], which discussed tangible user interfaces since it is psychologically very similar to user interfaces in immersive technologies. The results of that study showed that tangible user interfaces are good at inspiring creativity in designers and encouraging them to recontextualize the problem into their own understanding. While they were primarily focused on architectural design, they do show that immersive technologies show promise in aiding all collaborative design, if they are not used too early in the design process.

2.2 Future Applications of VR Technology

Bishop and Fuchs [33] summarize guidelines, including visual and audio cues that have since been implemented in many modern VR software to increase presence and limit motion sickness. They also call for a system of sharing hardware, software, and scientific results to help propel the research in virtual environments. Many of the proposed guidelines have become commonplace and are taught to virtual environment creators as a part of improving presence.

Churchill and Snowden identify some difficulties in collaborative design that could be exacerbated by immersive technologies: information exchange between asynchronous users in managing who needs what information and what information is sensitive, ensuring a shared vision of ideas, workflow, and responsibilities, and non-verbal cues as a part of negotiation and communication [34]. These complications do not prevent the use of immersive technology in design, but they should be considered in the systems that use the technology.

Fisher presents several systems [35], including some early head mounted displays, before the author proposes what he saw as the future of the technology. Fisher foresaw immersive technology being used for entertainment, in architectural design, and telepresence, and these are the industries that have committed most to the technology.

The most recent of these papers to discuss the future is [36] which widely talks about the future of CAD systems including the future use of virtual reality in CAD design. It suggests that existing CAD systems should fully integrate immersive technologies to be as robust as the traditional mouse, keyboard, and monitor.

While it is impressive how many papers dating back over 30 years have seen the future of this technology and predicted its maturation, the body of research into these ideas could still use more research to fully confirm or deny their hypotheses.

2.3 Virtual Reality in Mechanical System Design

An early attempt at an HMD is shown in [37] along with relevant psychology to immersive technologies by Benford et al. They believed that distributed virtual reality systems would be beneficial because humans innately communicate and socialize in three dimensions but noted that certain psychological factors had to be considered. The common term for these psychological factors is presence which has been previously discussed in this paper.

An experiment was developed and performed by Bochenek and Ragusa for the US Army. The purpose of the experiment was to study whether military personnel better understood a design review using conventional presentations or using the immersive CAVE system. The statistical results were inconclusive, but researchers believed that participants were distracted by the technology at first and suggested doing another study where participants could be introduced to the technology [38].

Daily et al. [39] discuss their difficulties simultaneously transmitting audio during a General Motors vehicle design review. Unfortunately, they ran into a significant amount of trouble, and most of the paper discusses their problems with the audio and what they attempted to do to solve them. Luckily, there are far more audio transmission technologies available today that they did not have access to in the year 2000 when this experiment was performed.

Lehner and DeFanti [40] developed a facility to enable distributed design reviews of ground vehicle design. The authors report on the configuration of the facility but do not provide insight regarding specific design tasks. Specifically, the authors do not report on the impact that a facility has on engineering design tasks of complex systems.

Software developed to aid in the conceptual design stage is discussed by Noon et al. in [41]. In it, they propose software that uses primitive shapes and existing models to brainstorm new designs. Intentionally, the software is not very exact, but it allows for rapid model generation which is more important in the conceptual design stage. In the experiment, the software is limited to only one HMD and one local computer which do not aid in remote collaboration, but it works as a proof of concept for incorporating virtual environments into the early stages of design.

3 Research Opportunities

From the review of literature three key areas are identified:

3.1 Mechanical Design Reviews

Researchers in architecture have developed software, performed exploratory studies, and completed data-driven experiments to evaluate the use of immersive technology in design [27]. While there have been demonstrated use of immersive technologies to support mechanical engineering design, there is an opportunity to understand past studies and develop protocol for studies in the domain of mechanical design, specifically for the design of next generation ground vehicles. There are enough differences in the approaches and necessary tools between the subjects to warrant independent research.

3.2 Integration of Current Immersive Technology

Many of the studies and experiments discussed in this literature review are over a decade old. Immersive technologies have advanced significantly since their publishing so much that simply repeating the studies with new software and hardware in current infrastructures could present meaningful new results. Additionally, many of the studies focus on static CAVE systems as their immersive technology when current HMDs are available at lower prices and more functionality with haptic controllers. Increased access to immersive technologies could allow for studies with more participants and increased scopes.

3.3 Formal Studies

Only a few studies in immersive technology report any data results, and even fewer demonstrate significant results. The RAVE design review in [38] is the only one that used more than a dozen participants, and their results were not considered statistically significant. Many of the architectural studies that reported experimental results had only a few participants, and the conducted experiments yielded results that are not transferable to mechanical design. Future studies should focus on conducting robust experiments with larger numbers of participants so that results can be considered more representative. Additionally, since many of the studies discussed in this paper largely reported anecdotal data, future studies should be conducted in manners that focus on collecting repeatable, quantitative data that can more easily be abstracted and generalized.

4 Design Review Use Cases

From the research into the state of the art, some potential use cases for immersive technology were determined for future targeted research. Each use case has specific software and/or hardware that is best suited to the scenario and fits within the DOD Acquisition process.

4.1 Situation Analysis

In the Materiel Solution Analysis (MSA) phase of the defense acquisition process, a situation is analyzed in search of problems and potential solutions to those problems. VR presents an opportunity to easily view these situations with operatives or experts to find inefficiencies without endangering themselves or the mission. From this analysis, a materiel need can be identified, and an Initial Capabilities Document can be made to further investigate solutions.

To solve a problem, people need to know that there is a problem and what is needed to solve it, and with immersive technologies, designers can unobtrusively watch view the situation searching for mistakes and inefficiencies. Some situations are too dangerous to send engineers to investigate for inefficiencies or problems, but with the ability to recreate scenarios virtually and experience them with immersive technologies, engineers can be in the middle of the action without risking themselves or the objective. For example, engineers could virtually follow first responders through the exercise of responding to a fire and observe methods and tools that are used to address the situation (see Figure 2).

Figure 2: Observer (purple) Watching a first responder (grey) in a virtual environment that would otherwise be dangerous.

Fires are normally too dangerous a place to send non-trained individuals, but in a virtual environment, they are not risking their own or anyone else's life by spectating. To make this situation useful, the technology would need to include a small 3D camera to capture the dangerous situation, immersive technology to put the engineer in the situation, the ability to tag objects with comments, freedom of movement throughout the scenario, and communication with experts to understand the situation at a high level. Further data can be collected from reviewing the footage with the expert and recording where they went, looked, and how they reacted in situations that might be subconscious or just not think to say. These situations could also be created with simulation experts using a VR creation software such as Unity. This requires more work to be done, but the data can be used again in later parts of the acquisition process.

By using immersive technologies in this manner, simple problems can be solved that otherwise would never even be found. While it is often that people recognize big problems and report the need for a solution, or that higher-ups recognize the problem, smaller problems can remain hidden without a trained individual to recognize them. Industrial Engineering is founded on the idea that trained individuals can find inefficiencies that can greatly improve the effectiveness of processes when given the chance to observe them. The best part of this tool is that it can be reused after the problem is identified.

4.2 Requirements Gathering

After identifying the problem, designers can begin to ascertain the requirements of the solution. This is a key process in the Technology Maturation & Risk Reduction (TMRR) phase of the acquisition process. With a simulated environment including the problem, the designers will be able to create more requirements and more precise requirements than by interviewing the operators alone. Gorsich performed some experiments with this same intention in [42]. These improved requirements can then be well documented for the System Requirements Review.

With this technology, engineers will be better able to understand problems that they have no personal experience with. To gather customer requirements, engineers can see the problem in a virtual environment of the customer's design. For complex situations, this can help convey large amounts of information to the engineers in a very descriptive way. For example, instead of stating that the road conditions will be rough, the engineers could see for themselves that the dirt roads are washed out, which can better convey the road conditions without requiring as many questions as before. For some complicated situations, this can be worth the additional effort to create the scenario because the engineers will know more about the situation and have the option to check back with the virtual environment with any additional questions they might have.

To best take advantage of this technology, the immersive technology would need tagging of virtual elements, audio cues or narration, dynamic object opacity, scaling tools, movement, and recording for the device positioning and movement for playback. The comment tagging will allow the engineers to document any observations they have. Audio cues/narration allow for the use of multiple senses that could be important or to include expert knowledge in an unobtrusive way. Dynamic object opacity and scaling tools allow engineers to see the problem from an otherwise impossible perspective. Recording of the scene and device movement and positioning can help engineers to understand both other engineers and experts' subconscious or at least non-stated observations. These tools not only recreate the problem scene but elevate it with otherwise impossible tools for greater analysis.

This technology is more than just a game; it provides resources that streamline and improve the design process. To borrow the firefighting example from before, most engineers do not have experience firefighting, but with immersive technology, they can gain that experience in a way that can give them the information they need to solve a problem. They don't need to ask one by one about each step the firefighter takes, and they don't need to ask them to describe each scene in detail. That information is valuable, but it can be too much at one time for the firefighter and/or the designer. A simulated environment answers those questions instantly and permanently which allows designers to ask more probing questions into why they do things and what they can do differently that aide in finding a better solution.

4.3 Conceptual Design and Tradespace Exploration

In the conceptual design phase, tradespace exploration is commonly used to search a solution space, populated by various solution concepts, for optimal solutions. In the process, also called Analysis of Alternatives, stakeholders iterate through the available options and attempt to determine the solution that best satisfies their objectives. Currently, the tradespace exploration process is supported using 2D visualizations such as radar plots and bivariate graphs. From these visualizations, tradespace decision makers determine the trade-offs each option presents between objectives. However, due to the large amounts of information presented between the graphs and plots, it can be difficult to distinguish the actual changes and trade-offs between options. To adequately conduct tradespace exploration, decision makers need to fully understand the trade-offs that will result from a certain decision.

Thus, immersive reality interventions could be implemented to help decision makers understand the changes and trade-offs between solutions. One such intervention would be to immerse decision makers within the tradespace, as if they were surrounded by a point cloud of potential solutions. This could allow users to understand how densely or sparsely the tradespace is populated in a region, or to identify various related or otherwise similar solutions to the solution being discussed. Another potential intervention would be to conduct tradespace discussions through VR, especially for cases with distributed teams. This would allow for easier discussions and potentially more optimal outcomes, as users would be more cognizant of the fact that they would need to make decisions that optimize all objectives, rather than just their own specific objective. Immersive reality interventions could also be used to demonstrate the changes or trade-offs between solutions. Haptic feedback, coupled with VR visualizations could be used to demonstrate resistance to change or the cost of making a change in any objective. By making the changes between solutions or objectives more evident, decision makers can more easily assess the benefits of a suggested solution and make optimal decisions.

4.4 Design for Assembly and Maintenance

In the Engineering and Manufacturing Development phase, designs are reviewed to ensure that they fulfill the customer requirements and that they are ready for production. This is where the input of maintenance technicians and manufacturing engineers is valuable to ensure the design can be assembled and maintained efficiently. While this is already common practice employed with drawings, CAD models, and guidelines, immersive technology can allow for the virtual recreation of these activities in a way that is easy, intuitive, and gathers all the necessary knowledge for the Critical Design Review (see Figure 3).

Figure 4: Mechanic virtually performing routine maintenance on a new vehicle model.

Design for assembly and maintenance are important parts of mechanical design, and with immersive technology, engineers can virtually check how easy a solution is to assemble and maintain. With either augmented reality or virtual reality, users can easily attempt to do all the functions necessary to assemble and maintain a part to ensure that none of its functions will be a problem during production or after. While planning for maintenance is already a part of the design process, it is difficult to tell how easy the task will be until the user attempts to do it with their own hands. Only with physical or virtual use can the engineer notice a lack of room for tools or even hands to fit in the spaces necessary. Either with a virtual tool in VR or a physical tool in AR, users can physically perform the tasks of assembly and maintenance at any point of the design process with the CAD file that they already have.

Many devices fail due to improper maintenance. This can partially be because routine maintenance was an afterthought and therefore wasn't made easy enough for users to want to do the required maintenance. Many of the mechanisms that still work today are the ones that were made easy to maintain. With immersive technologies, we do not need to require maintenance technicians to read and visualize drawings to evaluate maintainability, they can simply put on an HMD and do their job like normal. This dramatically simplifies and accelerates the evaluation of the device for maintainability and manufacturability.

4.5 User Feedback

The Engineering and Manufacturing Development Phase is the last opportunity to make major changes before the final design is sent for productions, but the design is finished enough to start receiving feedback for users thanks to immersive technologies. With the CAD models of the prototype, designers can display it in a virtual environment for users to view and even interact with. This can be done more quickly, more securely, and cheaper than waiting until after a prototype has already been manufactured by just sending the file securely to the people who will actually be using the device. This feedback can be valuable for the Initial Operational Test and Evaluation before the Critical Design Review.

Product users may have little to no say in the design of the product, but immersive technology provides engineers with the ability to get feedback whenever they want, even before a prototype has been built. Being able to present users with a virtual prototype via immersive technology gives engineers information about how users will interact with it and allows for user feedback. Since this only requires a 3D model, users can be consulted at early stages of the design process. In the case that the customer and user are different people, customers can also give feedback to design in the same way, at the same time.

There are many times and reasons that design solutions can fail, and immersive technology can help eliminate a couple of these reasons before it is too late. One reason that designs fail before production is that the customer does not like the aesthetics of the design at the approval point which can get the entire project cancelled. By getting feedback from the customer before this point, the designers have more time to fix the problem before this critical decision and potentially save a good project. Other projects solve the problem, but the design is not configured to the operators of the solution who may not like some aspect of the design. For example, when members of the military are working at night, they need to be able to read their instruments. However, the obvious solution of adding a light may not work because said operators are afraid of others seeing the light. This is based on a real product given to them and highlights a problem of communication where the users could have given valuable insight onto aspects of a design. Since they were not consulted, the device often does not get used as planned. With immersive technology, it is easy to send a design to a future device user who can give vital feedback before production even begins.

4.6 Immersive Simulations

All designs must be tested prior to the Critical Design Review often including simulations, but with modern simulation and virtual reality technology, these results can now be shown in action rather than as results on a form. This ability is just the combination of already existing technologies for clearer communication of test results. Combined with the virtual environment that contains the problem scenario that has already be used in prior use cases, product managers can get an immersive, accurate representation of the final product before prototypes are even created much less operationally tested.

As a part of design reviews, management can now view the entire design in action in the working environment thanks to immersive technology. The ability to view and virtually interact with designs has already been discussed. However, immersive technologies allow for instant simulation of the design in use. The design can be moving in real-time to show how it works for design reviews. This, combined with virtual environments, can show how it works in its working environment. This can help better communicate how the device works and how it is expected to work in use, both of which are critical factors in design reviews. The data required should all already exist if the previous use cases including the virtual environment are incorporated. The CAD model and simulations are already standard practice before production. Immersive technology has the ability to incorporate other non-optical sensory feedback such as audio or haptics if the presenter chooses which provides new multidimensional presentations that were not possible before. With some presentation tools such as gesturing, highlighting, and commenting, the design review can become a faster and clearer presentation.

4.7 Virtual Training

After the design is approved, there are still places for immersive technology to aid it, primarily via virtual training in the Operations and Support phase. Giving tradespeople the ability to practice constructing and maintaining the design in a no-risk scenario provides a great environment for learning. The training can even take place before production has begun to shorten startup time. Some companies such as Siemens are already working on implementing virtual training modules into their CAD software. This does require the creation of extensive training modules, but by starting training sooner and training without the cost of real resources, this ability provides significant advantages.

5 Conclusions

Immersive technology in collaborative design is an important area of current research, and there is still room to expand the state of the art. Researchers in the field of architecture have made a concerted effort to investigate immersive technologies. Many older papers have already created guidelines and suggestions for research in addition to the gaps listed here. However, the topic also needs to grow in depth with data driven research in addition to exploratory search. Immersive technology is already available and should be used to advance mechanical design. From the use cases, studies need to be developed and a series of experiments should be run to determine the impact of modern immersive technology support.

It is important to evaluate the use cases, conduct formal experiments, and complete case studies to understand the impact of immersive and virtual tools on engineering tasks. The use cases provided are not an exhaustive list, but target studies are required to understand how new technology can effectively be used as mechanism systems and development processes change. Some of these use cases can even be fed into each other such as those involving a high-fidelity virtual environment. It would only need to be created once but can be reused in several stages.

The future of design will certainly include immersive technologies in some way, but these are some areas that immediately show promise even with current technology.

While there have been advances in lower cost, smaller technologies dedicated efforts to understand how the immersive technologies can be used to increase distributed collaboration in complex systems design is needed. Specifically, a shift from using immersive technology because it is a trend without evaluating the benefits and limitation is needed. The experimentation process proposed by Gorsich [42] should be a first steps in evaluating how to best leverage virtual reality for the development of next generation ground vehicles.

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