VR-based product development process: opportunities and challenges in the automotive industry*

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ABSTRACT

In the product development, the success of a manufacturing strategy is achieved by specifying a manufacturing process that it can be produced with minimal impact. In the automotive industry, to detect late, i.e., already during manufacturing phase, issues on customers preferences on new vehicles, physical ergonomic issues, or problems on usability of a product has a high cost of correction and long the time to launch a new product. Thus, given the complexity of products that are under development, designers must perform a number of procedures to guarantee that the finished product fits customer demands and is accepted by the market. With the emergence of low-cost virtual reality devices, the automotive industry is adopting virtual reality for several engineering processes and support everyday engineering. The patent filings have boomed since 2016, in a technology space that is rapidly evolving, offering opportunities to enter an area while it is still young. Virtual reality benefits the product development process by saving costs and time, closing customers, improving interactions, avoiding prototype transportation, optimizing the assembly line, improving the performance and well-being of the user, mitigating hidden dangers, stimulating novel insights and increasing team collaboration, and feeling of engagement, among others. However, certain constraints must be overcome before the technology's possibilities can be fully harnessed. The challenges faced by VR-based processes are the lack of realism due to unnatural tactile and visual interactions, latency and registration issues, communication difficulties between teams, unpleasant symptoms, issues on depth, haptic, motion and movement perceptions, cybersecurity, cybersickness, lack of intuitiveness, and partial control over the user's moving around, among others. While there are still challenges to be addressed until industries can fully benefit from the technology's potential and these constraints prevent virtual reality from fully replacing conventional automotive product development in the near future, it is a valuable contribution to the process. In this context, this work discusses the opportunities and challenges of virtual reality-based product development process in the automotive industry. A better knowledge on this subject may provide a reference for decision-makers, practitioners and researchers as they continue to develop innovative immersive solutions in the product development in the automotive industry.

KEYWORDS

virtual reality, product development, ergonomics assessment, market research, usability testing, automotive industry

1 VR-based automotive market research, ergonomics assessments and usability testing

We compiled the challenges and opportunities identified by literature reviews on VR-based car clinics [1], on physical ergonomics assessment [2], and VR-based usability testing and design reviews [3]. Table 1 summarizes our findings.

Table 1. Summary of the opportunities and challenges identified

	Opportunities	Challenges
VR-based market research	• Cost and time savings • Proximity to customers • Flexible interactions • Avoidance of prototype transportation	• visual spatial • graphic quality • depth, haptic and motion perception • physical collision/ movement perception • color and texture definition • sound feedback • interaction/ manipulation • intuitiveness • cybersecurity • cybersickness
VR-based ergonomics assessment	• Cost and time savings • Optimization of the assembly line • Improvement of performance and user well-being • Mitigation of hidden dangers	• Simulation of sense of touch and physical resistance • inconsistency between user's movement and virtual animation • high setup and maintenance costs • information on the ROI • reduced sense of immersion • facial tracking jeopardized
VR-based usability testing	• Redesign cost and time savings • Stimulation of Novel Insights • Increased Collaboration • Intuitive Interactions • Increased Safety	• Lack of Realism due to unnatural tactile and visual • Latency and Registration • Teams Communication Difficulties • Motion Sickness

2.1 Opportunities and benefits

In terms of market research, virtual reality is acknowledged as a method to improve costs, timing, and physical prototype relocation required for the research. Cost saving is one of the broadest benefits, since virtual prototypes are less expensive to build, demand no storage space, lowers the costs of delivering physical prototypes and avoid user travel. Virtual prototypes also decrease rework and boost productivity and survey performance. The time to develop a virtual prototype is minimal and can enhance the overall review process; virtual prototypes can be generated earlier than physical property, improving development schedule. Besides, physical prototypes are challenging to handle and move, so VR enables trials that is challenging and costly to carry out in physical car clinics, such as research with large numbers of participants or in multiple surroundings, such as alternative store setups. Thus, immersive clinics might be carried out in more appealing atmosphere than is afforded by physical survey, with VR providing the buyer the impression that they are in a friendlier location, such as a vast showroom or open atmosphere.

In terms of usability testing and design review, virtual reality benefits the conventional design reviews and usability testing processes in two key aspects: over conventional CAD models on screens and over physical prototypes. The most frequently cited benefit over CAD on screens is that the visualization of products from different viewpoints and on a true scale stimulated novel insights. A conventional review is carried out on a computer with CAD tools on a flat screen, that not always satisfy all the criteria for functional and ergonomic validations of complicated 3D models. Virtual reality allows more novel modes of visualization and interaction to enhance engineering design reviews in this situation. Also, the opportunity to observe a product from different angles and with more detail might generate innovative discoveries. Some studies found that visualizing planes in a virtual reality environment gave participants a better understanding of the spatial relationships between product components, as well as the interaction space around the assembly line, allowing the design team to understand the operating clearances in real size. The possibility of new visualization facilitated overall mistake detection. When compared to a standard CAD software approach on a flat screen, participants are more likely to spot faults in a 3D model inside an immersive virtual reality environment. The benefits of combining fully digital CAD models with physical components of hybrid prototypes, such as the cockpit gear utilized in the automotive industry, are also emphasized. With the addition of the physical model, designers can evaluate their designs both visually and tactilely. This adds a further physical dimension, allowing designers to not only "see" their designs, but also "touch" them, providing designers with simulated interaction solutions in the early stages of design. The advantages of improved collaboration and engagement were also frequently cited. Industrial design reviews and usability testing are complex processes involving a variety of stakeholders, including designers, engineers, and end users. In conventional review process, CAD is a communication tool to transmit design ideas and enable a better common understanding among diverging perspectives. The high focus provided by VR-based reviews increases a feeling of team engagement. In the conventional process, design teams cluster around conference tables with laptops, mobile phones, and paper notes while one person manipulates the design on a 2D screen, so maintaining team attention is challenging when battling with device distractions. The virtual environment allowed the team to move away from the traditional conference room and into a creative area with fewer distractions. So, the design discussions in the immersive environment increased team engagement, resulting in better interactions and fuller participation in decision-making. VR-based design evaluations and usability tests might be more natural, friendly and intuitive for non-CAD specialists. While CAD software does not allow the intuitive manipulation of 3D models by users without a CAD or computer science background, interaction in VR environments is generally simpler. Because of the high level of immersion provided, interactions with 3D models are regarded as more intuitive and "natural" for non-CAD specialists, enabling a considerably faster entry into the design review.

In terms of advantages of virtual reality when compared to the conventional review process of physical prototypes, the most frequently noted advantages are cost and time savings for redesign. Industries may employ virtual prototypes to save money, minimize redesign time, and expedite time-to-market. Prototyping is an essential step in the product development process, but after building a product model, testing its design and functionality requires time and money. Because physical prototypes and mock-ups may be replaced by their virtual counterparts, virtual reality improves design verifications and the review process, which might contribute to cost savings for manufacturers. The principle of "simultaneous engineering", in which elements are designed and tested virtually concurrently with vehicle development, might be achievable with, and potentially strengthened by, the use of virtual reality. As an example, in automotive industry, a type of control could be created early and parallel to the development of a new car model and tested within a virtual car model worldwide. So, the cost of redesigning a model can be reduced if the type of control can be changed in the course of development, enabling the creative departments to produce and test novel concepts without disrupting the conventional flow of product development. Furthermore, since VR allows to replace physical review meetings for immersive technical discussions, the reduced travel frequencies might save costs. Also, for dynamic usability testing, such as driving a car, virtual testing increase the participants safety, that are not subjected to actual risks since a vehicle collision while driving, or a car accident involving passengers, would not occur in the virtual environment.

2.2 Challenges and limitations

On VR-based market research, visual–spatial and graphic quality are the most significant issues in a virtual clinic. Since the market research's goal is to determine style acceptability for customers and the external design and vehicle size are important factors in consumer decisions in the automotive business, the prototypes must visually be as realistic to a production vehicle as possible. The graphic quality must be defined so that consumers do not lose fluidity. If this challenge is not addressed, respondents may have the feeling that they are watching a 1930s movie, with visual motions that are slower that the brain requires to give the user the impression that they are in a real world. So, the virtual prototypes must have a sufficient quality to customers provide relevant input in immersive car clinics. Cybersecurity, product manipulation/interaction, depth perception, and color and texture have the potential to cause significant effects on immersive car clinic applications. Due to product confidentiality, car clinics are held in a secure setting, so cybersecurity must be carefully considered. In relation to manipulation and interaction in a virtual car clinic, customers should be able to roam around the item on their own, achieving the higher perceived amount of information required between product and customer. Environments that allow customers to wander around the virtual asset, which simulates the same experience as a conventional car clinic with a physical asset, should strengthen the association. To decide how realistic this experience should be, a balancing between the needs of a larger VR area and the advantage of more immersed clinic customers should be undertaken. Many simulation opportunities, such as opening a door or manipulating mirrors, may be accomplished virtually, but these do necessitate refined virtual prototype and potentially more robust equipment to process such data without losing customers' feeling of movement. Customers prefer not to approach the car too closely when depth perception difficulties are most apparent; so, market research for exterior design testing experiment may not be an issue. Customers may be bothered by vehicle interior feedback because most customer interfaces and verifications are performed at close proximity to the stimuli. The specification of the Head-Mounted Display (HMD) may also lessen depth perception concerns, so it is critical to determine the best hardware depending on the intended survey outcome. With physical stimuli, different textures and colors are presented with small samples or 2D images, rather than in a vehicle environment, because this would considerably increase the complexity of stimuli to be done. Other difficulties that impact the immersive car clinics are the VR equipment intuitiveness, cybersickness, haptic, and physical collisions. In car clinics, motion perception, sound feedback, and the physical environment needed by VR hardware are irrelevant since clinics are held in workshops that require space for four to eight vehicles, which is far greater than what VR hardware requires, and physical prototypes seldom give sound feedback.

In terms of ergonomics assessment, Ref. [4] observed a contradiction. Despite the consensus on the benefits of carrying out the assessments early, only a few VR-based physical ergonomics analysis occurs during early product development. The majority of cases oriented to pre-designed production processes, when all resources (devices, facilities, equipment, etc.) are fully installed. A possible reason is that virtual reality imposes additional challenges that restrict its widespread adoption. The heavy emphasis on the sense of touch during assembly processes and the expectation of a physical resistance when interacting with virtual structures can often not be adequately simulated. Additionally, rather than improving the sense of immersion, VR can reduce it, since some individuals may feel less present in a virtual environment or may even respond negatively to virtual reality use by having motion sickness-like symptoms, which can impair work performance. As a result, the facial validity of motions tracked in virtual reality may not be as well established as it is in real-world tests on prototypes.

In terms of usability testing, the unnatural tactile and visual senses result in lack of realism, that difficulties interactions between individuals and virtual prototypes. Haptic feedback and multimodal interactions are still problematic. The movement of participants' hands could not be well simulated and positioning offset occurs frequently, and users reported issues with virtual object feedback when compared to external device motions, such as steering-wheel twisting. Another issue is that the sense of reach and the dimensions of virtual items do not correspond to physical interaction features, such as buttons or flat surfaces that mimic multimedia screens. Given the significance of natural human connection with a virtual interface, haptic devices such as gloves, suits, and others may strengthen the sensation of immersion. Besides the touch sense, the lack of realism is caused also by visual sense issues. The readability in a virtual prototype system can be troublesome due to the HMD's low display resolution. Due to complex interaction systems with a substantial amount of visual information, high graphical representativeness is essential. Also, a major issue is that employing VR without an auxiliary device, such as hand-tracking sensors, may influence user perceptions and, as a result, test findings. In usability testing with physical prototypes, each participant's perception of a product's depth, reach, and dimensions is spontaneous. In virtual reality, however, the user desires touch with physical devices to handle objects in the virtual world; thus, visual calibration and positioning algorithms are needed to provide an accurate user experience. When human interaction beyond visual verification is desired, virtual prototypes are challenging. When creating functional virtual prototypes that are designed to offer visual, tactile, and aural feedback, the difficulty is to produce a high-fidelity virtual prototype that has the same features as a physical prototype. Geometric component qualities, such as high-fidelity colors and textures or part structure animations (such as when a vehicle's door opens), require powerful hardware to process data within the virtual reality to ensure a reliable experience for the immersed individual. Since it is critical to assess the participant's emotional reaction while designing the qualitative metrics of a usability test, occlusion is also challenging. Virtual surroundings might diminish some sensations throughout an activity, such as user happiness or dissatisfaction. Due to the inability to watch the participants' facial behavior, which the head-mounted display was partially hiding, the moderator did not fully observe the participants' emotions. Another difficult is the time between head movements and viewing the scene, i.e., latency and registration issues. When interacting with mixed physical-virtual prototypes, study participants mentioned a dimensional discrepancy between the virtual and physical aspects of the prototypes (for example, the cockpit's physical wheel and the virtual air conditioning control). So, the need to calibrating the position and visibility of virtual objects with physical prototypes was identified as a barrier. The difficulty is the time it takes to calibrate the system, given that calibration modifications are dependent on the user's participation. VR-based design reviews of complex CAD data often suffer from communication issues between virtual reality users and team members who observe from an outside perspective (e.g., a TV screen). Therefore, spoken descriptions are often insufficient to express details on a component. Also, while immersed in VR, people reported motion sickness and unpleasant symptoms, such as nausea or headache.

3 Final Considerations

The automobile sector has been under pressure to reduce time to market and increase product definition accuracy. Virtual Reality is a powerful tool to engage with customers from the early stages of product development through after-sales support, as well as might be a cost-saving measure and shorten cycle time in the automotive industry. The devices remain relatively expensive and technical constraints exist, but the price of VR equipment decreased year on year, technological constraints have been reduced, and new features have been developed, resulting in the increased development of VR applications. Thus, our findings provide a reference for decision-makers and researchers to develop novel solutions for the industrial product development process.

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