WHAT DETERMINES VR INTEGRATION IN DESIGN PRACTICE? AN INVESTIGATION OF INDUSTRIAL DESIGNER'S ACCEPTANCE OF VR VISUALISATION TOOLS

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ABSTRACT

Emerging visualisation tools based on eXtended Reality (XR) platforms offer designers new possibilities and benefits, attracting increasing interest from academia and industry. However, as the users and consumers of these tools, practising designers' perceptions of XR visualisation tools need to be further verified as they shape the tools' acceptance and integration in the industry. This paper investigates industrial designers' acceptance of VR visualisation tools using the Unified Theory of Acceptance and Use of Technology (UTAUT) model. Semi-structured interviews were undertaken with 12 designers from 3 countries to discuss their attitudes, motivations, experiences, and expectations regarding adopting VR visualisation tools as professional tools. The study highlights key opportunities to promote VR integration in industrial design as the tools' practical capabilities to support design performance and the social influence of stakeholders and peer designers on the professional use of VR. The main barriers lie in designers' expected effort to learn and use the tools and the investment and upkeep of VR systems and facilities in the industry. The paper concludes with recommendations for reaping benefits and overcoming barriers.

Keywords: Virtual reality, Industrial design, Visualisation, UTAUT

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1 INTRODUCTION

Immersive visualisation tools based on eXtended Reality (XR) are emerging as the platforms and hardware devices advance, facilitating new design workflows and possibilities. With the increased popularity of XR technologies, many design visualisation tools on augmented reality (AR), virtual reality (VR), and mixed reality (MR) platforms have been positively reviewed and discussed in design education and industry (Cox et al., 2022; Kent et al., 2021). Studies show that AR/VR design visualisation tools offer various benefits to designers, i.e., bridging the 2D to 3D transition, enabling distributed collaborations, and fostering more intuitive engagement with stakeholders (Goethem et al., 2020; Novoa et al., 2022; Oti and Crilly, 2021). According to Tsai and Yang (2017), the selection of design tools primarily relies on designers' expertise, work experience, and creativity. In other words, the widespread adoption of a design visualisation tool in practice is closely connected to the designer's perceptions of the tool. Therefore, practising designers' perceptions of XR visualisation tools must be researched to validate the benefits proposed in the literature alongside further considerations for implementing them in practice.

This study investigates the attitudes, motivations, experiences, and expectations of industrial designers adopting VR visualisation tools as professional design tools. An interview study was conducted with twelve industrial designers to map the determinants of their acceptance of VR visualisation tools. The results highlight key benefits and considerations for industrial designers adopting and integrating these tools in their design practice. The study provides a reference to guide the industry in implementing VR visualisation tools and ensure designers benefit from the integration. Recommendations are given to help researchers in the field understand and improve the quality and implementation conditions of these tools to support the potential wider uptake of VR visualisation tools in industrial design.

2 EMERGING VR VISUALISATION TOOLS

It is well established that designers use visualisation tools to generate design representations for externalising, reviewing, evaluating, and communicating ideas (Cross, 2001; Goldschmidt, 1991; Ranscombe and Zhang, 2021). At the same time, the selection of design visualisation tools can significantly influence practitioners' creativity and collaboration performance and the quality of design outcomes (Tsai and Yang, 2017). Berg and Vance (2017) suggest that VR technologies enable users to feel physically located in a virtual environment beyond reality and provide a sense of presence. Some studies show that VR technologies and applications are mature, affordable, and stable for industry use (Berg and Vance, 2017; Kent et al., 2021). This study defines VR design visualisation tools as applications operated by VR hardware devices on immersive platforms, providing designers with sketching, modelling, prototyping, and rendering capabilities to create visual representations. This section presents an overview of the VR visualisation tools and the potential benefits they can offer in industrial design practice, alongside barriers to implementation.

The potential of VR sketching tools for professional design use has been explored since the 1990s in relevant design fields, i.e., architectural design and interior design. Research has shown that using VR sketching tools can positively influence a designer's cognitive performance, provide a sense of scale, and make the sketching experience more interactive (Rieuf et al., 2017). Laing and Apperley (2020) claim that VR sketching requires more development in terms of efficiency, integration with existing workflows, and typographic controls to be ready for professional design. Studies also imply that the cost of integrating VR into existing design workflows is considered a barrier (Berg and Vance, 2017). However, the cost of purchasing and maintaining VR hardware facilities has decreased (Kent et al., 2021). Many VR sketching applications are free or cheaper than PC and tablet-based design sketching tools, i.e., Adobe Photoshop and Procreate. Commercialised VR applications that can be considered for industrial design sketching uses, such as Gravity Sketch and Open Brush.

VR applications for design prototyping and rendering are further explored in existing literature compared to VR sketching. According to Kent et al. (2021), MR prototyping tools are ready to be adopted and implemented in the industry providing benefits in design creation and configuration, visualisation, knowledge management, integrated analysis, and collaboration. Other specific benefits

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are noted in the literature. For instance, VR visualisation tools for prototyping provide a sense of scale, support the design translation from 2D to 3D environments, and boost designers' interaction through the multisensory and multi-modal dimensional experience (Rieuf et al., 2017). MR prototyping tools also give designers greater flexibility to manipulate fidelity (Cox et al., 2022). Coutts et al. (2019) notice that VR prototyping tools are comparable to physical prototyping tools regarding the look and feel of the design. Some VR prototyping tools are emerging for professional design uses, i.e., Autodesk VRED and Microsoft Maquette. Traditional CAD rendering applications also enable extension into VR prototyping, i.e., KeyVR from Keyshot and SketchupVR for SketchUp. VR visualisation tools can also encourage more effective communication and facilitate multidisciplinary and distributed communication and collaborations (Berg and Vance, 2017; Novoa et al., 2022). Features for real-time multi-user collaboration can be seen in many VR visualisation applications, i.e., Autodesk VRED, KeyVR Connect, and Gravity Sketch Collab.

Existing studies on VR visualisation tools are conducted through systematic reviews, students' experiences in education settings, or surveys of VR experts or scientists. Research shows that VR visualisation tools are becoming available and have valuable potential in assisting design visualisation, decision-making, and communication. Some challenges of implementing VR visualisation tools in relevant design fields are also noted in the literature, i.e., technical complexity, implementation cost, and lacking tactile feedback (Coutts et al., 2019; Kent et al., 2021; Laing and Apperley, 2020). However, the practicalities influencing the implementation of VR visualisation tools in industrial design practice are complex and need further clarification to develop strategies for further VR integration. To summarise, while research demonstrates the benefits of adopting VR visualisation tools in design, practising designers' acceptance and perceptions of these tools should be investigated to extend our understanding of the proposed benefits and barriers to industry implementation.

3 INDUTRIAL DESIGNERS' ACCEPTANCE OF VR VISUALISATION TOOLS

Using the Unified Theory of Acceptance and Use of Technology (UTAUT) model proposed by Venkatesh et al. (2012), this study examines designers' acceptance of VR visualisation tools in industrial design, elucidating the opportunities and barriers to their implementation in practice.

3.1 Interview design

Professional industrial designers were approached to participate in a semi-structured interview study on their perceptions and experiences of VR visualisation tools. The UTAUT model was adapted to design the interview questions and analyse the designers' responses. The UTAUT model is an extension of the technology acceptance model (TAM), ascribing consumers' attitudes and behaviours toward technology acceptance and use to four determinants: *performance expectancy, effort expectancy, social influence, and facilitating conditions*. This study employs UTAUT as the theoretical framework due to its focus on the consumer use context (Venkatesh et al., 2012) to study the acceptance of VR visualisation tools among their consumers - industrial designers. The interview study analyses the determinants and their relative weight of impact on the current and potential adoption of VR visualisation tools in industrial design, from which the key factors under each determinant are highlighted for discussion.

Adapted from the UTAUT model, this study defines *performance expectancy* as the extent to which industrial designers perceive using VR visualisation tools as helpful in supporting their design performance. *Effort expectancy* considers the ease of learning and use as well as the technical complexity associated with VR visualisation tools. Based on peer and societal perceptions, *social expectancy* reflects designers' views on whether the professional use of VR visualisation tools is or will be an industry norm. *Facilitating conditions* are the accessibility of VR visualisation tools, resources, and infrastructure to support the tools. Participants' prior experience and willingness to use VR visualisation tools are adopted to monitor their moderating effect on designers' acceptance.

Industrial designers were interviewed separately via online conferencing. The semi-structured interview features questions on participants' willingness, motivations, professional requirements, and expectations of using VR visualisation tools. For example, questions on whether and where the participant considers VR visualisation tools can be useful for industrial designers. Other questions on the potential of VR

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visualisation tools to be mainstream design tools, the rationale behind the answers, and the participant's willingness to use or continue the use of VR visualisation tools in practice. Participants were also asked to describe their years of experience in their industrial design area and their prior experience with VR visualisation tools. In addition, other spontaneous questions were asked based on the information provided by each participant in the semi-structured interview. Interview data were collected as audio recordings with participants' consent and then transcribed for qualitative data analysis using Nvivo.

3.2 Participants

Twelve participants with various experiences from three different countries within the Asia Pacific area were recruited for the study. Participants' years of experience vary from less than two years to more than fifteen years. This study uses five years of experience to differentiate junior and senior designers for discussion. Participants are coded as P1–P12. Four junior industrial designers (P3, P4, P9, P11) and eight senior designers were interviewed. Six out of the twelve participants (P5-P9, P11) have prior experience using VR design tools. P5, P8, and P9 use VR frequently in some of their design projects. P6, P7, and P11 had limited experience with VR visualisation tools. Nine industrial designers work in mass produced consumer product design (e.g., home appliances, hand and power tools, electronic devices, farming equipment). P1 and P7 also work on UI/UX projects in practice. The other three industrial designers (P8, P10, P11) work in automobile design area.

4 RESULTS

Thematic analysis was used to identify the primary factors that influence designers' acceptance of VR visualisation tools in practice. The textual interview data was categorised against the determinants specified in the UTAUT model to analyse their impact on VR integration in design practice. Participants' comments regarding their attitudes and experiences with VR visualisation tools were then classified as positive or negative references based on sentiment keywords and context presented in the interviews. For example, P8's remark that "VR representation is more realistic compared to traditional tools and sketch renderings" was coded as a positive reference against *performance expectancy* and then further analysed in subsequent discussions. Likewise, P4's statement that "learning how to use the software would probably be the biggest hurdle" was coded as a negative reference against *effort expectancy*. This section begins by providing an overview of the results, followed by a thorough qualitative examination of the interview findings in accordance with the four determinants.

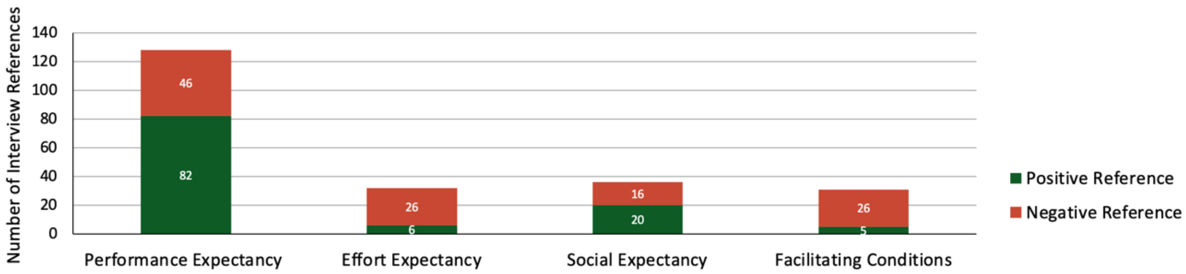

Figure 1. Participants' interview references on the UTAUT determinants

As shown in Figure 1, the *performance expectancy* of VR visualisation tools was most frequently mentioned among the four determinants. A similar number of references were made on *effort expectancy, social expectancy, and facilitating conditions*. Participants commented more positively on the *performance expectancy* and *social expectancy* of adopting VR visualisation tools and more negatively on the *effort expectancy* and *facilitating conditions*.

4.1 Performance expectancy

All participants made positive comments on the *performance expectancy* (see Figure 2), and ten also agreed that VR could become a mainstream design tool for industrial designers. Most positive remarks (59/82) and negative remarks (29/46) were made by the six designers with prior experience using VR visualisation tools, namely P5-9 and P11. Their positive-to-negative reference ratio is approximately 2:1 and 1.35:1 for other participants. The results show no evident association between designers' *performance expectancy* and their area of practice or years of experience.

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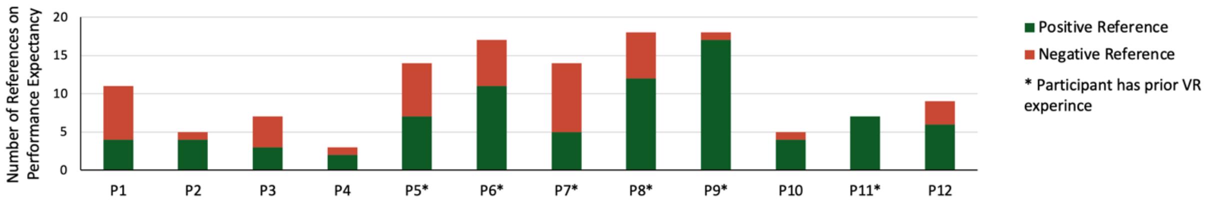

Figure 2. Participants' references on performance expectancy of VR visualisation tools

Results indicate that participants have a relatively optimistic outlook towards using VR visualisation tools to assist design visualisation, development, communication, and collaboration. Most participants agreed that using VR visualisation tools could facilitate more **interactive and effective communication and collaboration** among peer designers and non-designers, such as engineers, clients, managers, and other stakeholders. Some participants (P2, P6, P8, P9) noticed that certain clients do not respond well to many established design visualisation representations (i.e., technical drawings, design sketches, CAD renderings) due to a lack of design expertise to interpret the visualisation appropriately. As P8 mentioned, "clients can't imagine the 3D form from the sketch renderings". VR visualisation tools present clients with an immersive multidimensional view of the design adding "benefit to understanding and assessing it"(P11). According to P1, P3, P6, and P11, VR visualisation tools can provide real-time design manipulation and animation capabilities that allow designers to gain more specific and spontaneous feedback from clients during interactive design communication. As described by P3, designers can manipulate the product in various ways in VR visualisation tools, i.e., "turn it around, look at it, open it up, and disassemble it". Participants (P1, P7, P12) also noted that VR can be used to enhance product pitches to external customers, impress clients, and boost communication dynamics during design presentations.

Several participants (P2, P4, P7-9, P11-12) also suggested that VR visualisation tools can promote **distributed collaboration** as multiple designers can visualise, review, discuss, and change the design together in VR. For instance, P12 described the scenario as "designers are looking at a 3D CAD mode in VR and interacting with it in a digital-physical way to provide feedback or make changes on the model." Participants (P5-P9, P11-P12) also mentioned that the use of VR can **accelerate design iterations**, as it exposes design issues (e.g., form, aesthetics, dimensions, user experience) early on and allows designers to quickly validate the design from a multidimensional perspective. Compared to physical prototyping, VR visualisation tools offer more **flexible and cost-effective prototyping** options during the later stages of the design process, as stated by P6, P8, and P11.

In addition to the favourable aspects, participants shared mixed views on the effectiveness of the **immersive view** offered in VR visualisation tools. Some participants (P1, P5) suggested that the designer's view in VR is immersive but only allows one single view of the design at a time, which could be insufficient compared to multiple view windows available in most CAD modelling applications. P7 and P8 also mentioned that the view in VR can be unintuitive and "there are still some differences between the focal point and perspective in VR and human eye". However, nine out of twelve participants agreed that the immersive view in VR offers a more natural and accurate "sense of scale" and proportion of the design object, which is particularly important for designers when designing large scale products. According to P5 and P8-P10, the immersive display of design ideas in VR can assist designers in visualising and understanding the 3D form and ergonomics of the product, especially for organic-looking products. Besides, participants have different attitudes towards the **visual quality** of design representations provided by VR visualisation tools. While P1 and P6 emphasised that the visual quality provided by VR tools needs improvement to "match the real material textures", other participants (P8, P10) were optimistic about the quality of VR design representations. P10 suggested that VR could offer "an aesthetic perspective" that shows "how material, textures, colours, and finishes all work together." P8 suggested that VR representations can be rendered more accurate and realistic with "all kinds of materials and textures" available at the early design stages.

Participants also made varying comments on VR visualisation tools' **compatibility with established design workflows**. P4 expressed concerns about VR's compatibility, while P9 and P11, with prior VR experience, gave positive examples of integrating VR with digital sketching and CAD modelling. P9 described that he uses VR to visualise the design object to scale, then "bring it to sketch and work around that overall scale of the product". P11 mentioned that "it takes less than 10 minutes" to export CAD models to VR for presentation. P12 were also optimistic about the compatibility of VR sketching and CAD modelling because "you're already sketching in 3D in VR".

Participants raised concerns about the performance of VR visualisation tools primarily on **operational issues**, especially in the early design stages. Three participants (P2, P3, P9) questioned whether VR visualisation tools can interrupt designers' creative flow. P5 and P7 noticed a need for tracking accuracy and effective textual input methods. P5, P6, and P8 required more precise controls to work on finer details in VR visualisation tools, i.e., parametric features. Four participants (P3, P5, P8, P10) emphasised the significance of receiving tactile feedback from physical prototypes. P3 pointed out that current haptic devices utilised in VR may not provide an effective solution since "no one really likes wearing the gloves and being fully hooked up to play with the prototype".

4.2 Effort expectancy

Effort expectancy, referring to the ease of learning and using VR visualisation tools in industrial design practice, was identified as a potential barrier by participants that made mostly negative remarks on this determinant. Figure 3 illustrates that all participants except P6 commented negatively on this determinant, with five participants (P2, P3, P5, P7, P10) also making positive references. The ratios between total positive and negative references made by designers with and without prior VR experiences are similar, showing that prior experience has no significant impact on designers' positivity on this determinant. It's worth noting that participants without prior VR experience made twice as many references to *effort expectancy* as those with prior experience.

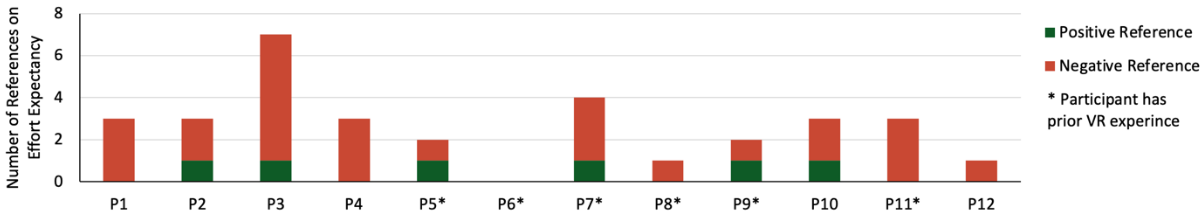

Figure 3. Participants' references on effort expectancy of adopting VR visualisation tools

In terms of the specific challenges related to *effort expectancy*, participants noted the **technical complexity** of VR visualisation tools, which may require a higher technical understanding and cause physical strain. Participants (P1, P2, P4, P10, P12) noted that VR could be considered "a bit exclusive" and "scary" to many people. As P1 suggested, "it is not sustainable to work in VR for 6-8 hours in a day". Some participants also expressed concerns about the effort required to prepare the **VR headset and environment for use** (P1, P7, P11), and issues related to VR hardware such as the ergonomics of controllers and the display of headsets (P3, P5, P8).

Additionally, the **learning curve** and **software training** for VR visualisation tools were identified as potential barriers. As P8 stated, "it (VR) has a slightly higher learning barrier for users, and that is also why some managers are reluctant to use VR", showing the learning curve of VR can affect designers and other project stakeholders to use VR in design practice. P3 expresses that VR visualisation tools need to demonstrate their value to design that is "obviously worth investing the time". Participants (P2, P7, P9) also revealed another challenge, namely the "lack of leading software" for VR visualisation and the constant "updating and changing" of features and "UI logic" compared to the more established tools, (i.e., Adobe suite for sketching and Solidworks for CAD modelling), requiring more time and effort from designers to learn and use.

However, participants also suggested some opportunities for lowering designers' *effort expectancy*. For example, P2 and P10 highlighted that the experience of VR technology (e.g., VR films and games) or other MR tools could help adjust designers' views on the technical complexity of VR visualisation tools. P5 and P7 suggested that the user experience with VR visualisation tools is "great" and "smooth" after the initial awkwardness. According to P9, VR visualisation tools save time and effort when visualising 3D objects compared to sketching tools.

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4.3 Social expectancy

Designers' adoption of VR visualisation tools is influenced by how the technology is perceived by their peers, stakeholders, workplaces, and the public, which shapes their *social expectancy*. As shown in Figure 4, all participants acknowledged the impact of these perceptions on their adoption of VR tools, with some expressing positive comments (P1, P5, P6, P10), some expressing negative comments (P2, P12), and others expressing both positive and negative remarks.

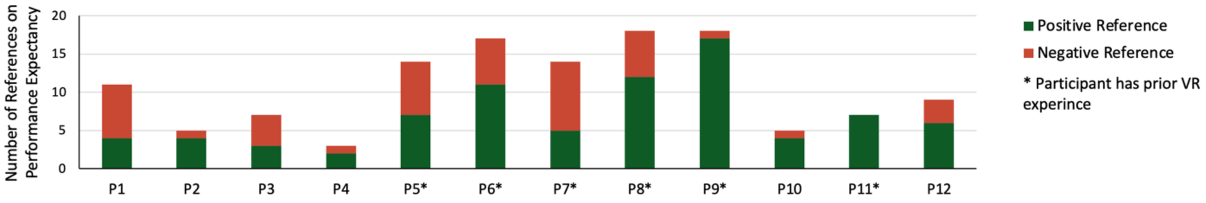

Figure 4. Participants' references on social expectancy of adopting VR visualisation tools

Participants expressed their **curiosity and willingness** to use VR tools with most considering VR integration as a "trend" in industrial design, but their sentiments on specific social factors on VR integration are mixed. The **willingness of clients and stakeholders** to use VR is also considered important by participants, but their opinions are divided. Some participants (P7, P8) observed initial reluctance among non-designer clients and "older managers" when reviewing VR design representations, but P11 claimed that many managers are excited to use VR.

Based on the **public image** of VR and advertisements and seminars on its professional uses, some participants perceived VR as a "powerful" and "valuable" tool for design (P1, P3, P5, P8), especially a "hot topic" in automobile companies (P8-P11). Conversely, P2 and P7 are concerned that the public and many designers perceive VR as an "overhyped recreational technology" and an "entertainment device" rather than a production tool. As some participants (P2, P3, P4, P11) stated, designing with VR is not a topic of conversation among colleagues in the workplace. Other participants (P3, P7, P11) noticed that the **development and uptake** of VR in general are slow, and VR needs to be "ubiquitous" to be adopted into design practice. For participants currently using VR in design practice, P9 pointed out that it is considered optional, and the usage is less than expected due to **project time and budget**.

4.4 Facilitating conditions

Figure 5 provides a preliminary overview of participants' references to the *facilitating conditions* for VR integration in design practice, with mostly negative comments (26 out of 31). Eleven out of twelve participants made negative remarks, with five observing positive changes in industry.

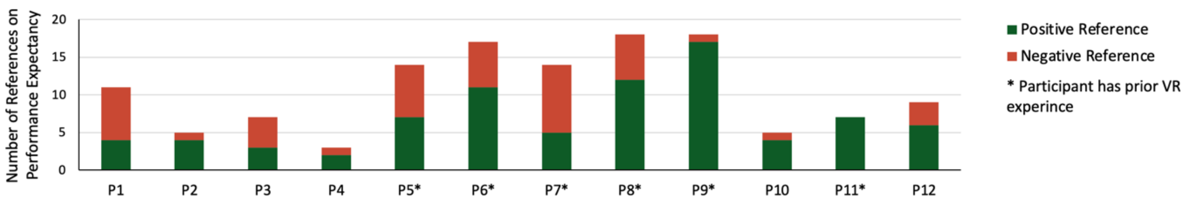

Figure 5. Participants' references on the facilitating conditions for VR integration

Participants (P2, P3, P4, P6, P7) commented on the **initial investment** in the VR system and equipment is considered high for designers and design companies considering the perceived value they can bring. Concerns were also raised about the costs of software applications (P1, P6, P12), as P6 described that the company stopped using VR due to the high "subscription fee". P2 and P12 noted the **upkeep of the system and hardware** after the initial investment as the technology evolves fast and devices can become "obsolete in a year". According to P8, the participant's company upgrades the system and headsets every two years, which can be challenging for smaller scaled companies. According to P4 and P7, the **infrastructure and accessibility** of VR tools at the workplace can be improved, which plays an essential role in adopting relevant visualisation tools. P3 and P11 also raised issues regarding the physical environment needed to operate VR visualisation tools and the **availability of VR specialists** to assist with learning and using VR visualisation tools.

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On the other hand, positive changes regarding this determinant were noticed by some participants. P1 believe that VR technology can create a "professional virtual workspace" for freelance designers, remote working teams, or small design consultancies to reduce the costs of renting offices. P8 and P11 work in the automobile design area and stated that VR is "to some extent used in every project", and P8's company is developing its own VR system and devices. P9 stated that the VR headset price has dropped, and the participant owns one for personal design projects. P10 was introduced to VR at work.

5 DISCUSSION

The interview results show that industrial designers have optimistic *performance expectancy* of VR visualisation tools as professional design tools and view VR integration as a conceivable trend in industrial design. Results confirm that industrial designers recognise the benefits of VR visualisation tools identified in the literature for supporting design performance. While existing literature emphasises the benefits of adopting VR visualisation tools in terms of effort expectancy (e.g., reducing 2D to 3D transition time), findings indicate the perceived effort for VR integration is high due to learning and integration issues. Regardless of the effort expected, industrial designers demonstrate curiosity and an increased willingness to adopt VR visualisation tools, indicating that designers prioritise *performance expectancy* when selecting a visualisation tool. Using the UTAUT model added new dimensions for understanding designers' acceptance of VR, namely *social expectancy* and facilitating conditions. Designers acknowledge that the social influences from peer designers, stakeholders, workplaces, and the public on their VR adoption in practice are moderately supportive. Results also suggest that more accessible and optimised VR infrastructure at workplaces is required for further industry integration.

Designers form more optimistic and explicit *performance expectancy* of VR visualisation tools from relevant prior experience. The findings on this determinant add nuances to consider alongside the proposed benefits in the literature. First, designers are keen to leverage the immersive design representation, interactive presentation, real-time multi-user collaboration, and animation rendering offered by VR visualisation tools to construct more effective communication with peer designers and other stakeholders. Designers also acknowledge that VR visualisation tools enable faster design iterations at a low cost. Specifically, VR sketching tools can expose design issues related to 3D forms and structures earlier than 2D sketching tools and ease the usual 2D sketch to 3D model translation. VR prototyping tools can moderate the necessity and costs of physical prototyping and related costs that occur in the process of design validations and iterations. Results show that industrial designers also recognise the advantage of having immersive design representations for understanding the scale, form, ergonomics, and proportion of the designed object, especially when designing organic-looking or large-scale objects. This finding is consistent with the suggestions from Rieuf et al. (2017). Immersive views in VR are natural and realistic but can be inadequate, as industrial designers may need to simultaneously view and validate the object from different angles. With some reservations, designers see the potential of the visual quality in VR design representations and the compatibility of VR visualisation tools with their current workflows.

Recommendations on *performance expectancy* to further facilitate VR adoption and integration in industrial design are as follows. The tactile feedback and textual input in VR visualisation tools should be intuitive and effortless. This aligns with a body of literature stressing the significance of tactile experience for using VR in design (Coutts et al., 2019; Laing and Apperley, 2020). VR visualisation tools should enable precise and parameter controls for industrial designers to work on small-scale products. The alignment between the VR view and the human view should be more accurate in terms of the focal point and perspective. Sensory experience with textures, colours, and lighting in VR needs to be more authentic.

In this study, participating designers with no prior VR experience paid more attention to the *effort expectancy* than those with prior experience regarding the adoption of VR visualisation tools. Results agree with Chauhan and Jaiswal (2016) that the *effort expectancy* of a particular technology can become a less significant determinant after using it. Designers admit that visualising design directly in VR would be engaging and enable effortless dimensional translation. However, senior designers may have built familiarity and loyalty with other established visualisation tools, so the effort needed to

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learn VR visualisation tools may seem unnecessary. Results also suggest that the overall uptake of XR technologies in the community is essential for designers to gain relevant experience, adjusting their views on the technical complexity of VR visualisation tools.

Recommendations given to moderate designers' effort expectancy are as follows. Accessible and beginner-friendly learning resources on VR visualisation tools and training opportunities are needed to ease the learning curve and cost for practising designers. UI/UX consistency and standards for VR visualisation tools should be established so designers' skills and knowledge of these tools can be transferrable. Leading VR visualisation applications in the field are to be provided so designers can easily target the appropriate software to learn. At the same time, VR hardware devices must be less physically demanding on the users and the operating environment, which aligns with Kim et al. (2020).

Some of these recommendations on learning resources may also help shift the *social expectancy* of VR as an entertainment technology. In addition to professional training, seminars, and appropriate advertisements of VR visualisation tools, results show that exposure to VR from peer discussions and use cases at workplaces promotes designers' VR adoption from the social aspect. Results also indicate that the attitudes and willingness of stakeholders (i.e., clients and managers) to use VR affect designers' adoption of VR visualisation tools. Designers consider the connection between the tools they use and the impressions they make to stakeholders. Participating designers also shared mixed sentiments on their experience of presenting VR design with stakeholders, and the acceptance of VR among stakeholders needs further validation. While some stakeholders are enthusiastic about VR integration, senior or more experienced stakeholders may prefer established design representations over VR.

The acceptance of VR among stakeholders affects not only designers' *social expectancy* of VR visualisation tools but also the actual *facilitating conditions* for industrial VR integration. Clients and managers can influence the design company's investment in VR systems and facilities and the budget for using VR in specific design projects. Designers suggest that the challenges themed on this determinant are primarily about the accessibility of VR visualisation tools which is linked to the design companies' budget for building and maintaining VR hardware systems, operation facilities, and software applications. Results also show that VR integration in certain design areas is ahead of others, i.e., the increased accessibility and use of VR in automobile design. Within this determinant, the accessibility and affordability of VR visualisation tools and infrastructure are key considerations for further implementation in industry, and the conditions are improving but have yet to be ideal. Apart from enhancing the affordability of the tools, results recommend targeted advertising to design company owners and managers demonstrating the economic value of VR integration in practice.

6 CONCLUSION

This study examines industrial designers' attitudes, motivations, experiences, and expectations regarding adopting VR visualisation tools in design practice. Literature suggests that VR visualisation tools offer various benefits to designers. Hence this paper aims to understand practising designers' acceptance of the tools to validate and leverage the proposed benefits alongside further considerations for implementing them in practice. Semi-structured interviews were conducted with twelve industrial designers from three countries to gain insights into the determinants of VR integration in industrial design. Insights were then analysed against determinants suggested by the UTAUT model: *performance expectancy, effort expectancy, social expectancy,* and *facilitating conditions*. Results clarify and extend the understanding of the benefits and practicalities of VR integration in industrial design and conclude with recommendations to guide further VR uptake in practice.

Results show that industrial designers acknowledge the proposed benefits of VR visualisation tools and are willing to adopt VR tools even if the effort required and the *facilitating conditions* are yet to be ideal. VR can be used for interactive and quality communication and collaboration with peer designers and stakeholders, enabling cheaper and faster design validations and iterations, and providing an intuitive sense of scale, aesthetics, and ergonomics. Some barriers are identified and translated into recommendations, i.e., improve visual quality and UI consistency, offer multi-view features, precise parametric controls, accurate tracking, and more authentic sensory input and feedback. Social influences

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and facilitating infrastructure are new dimensions for understanding VR integration in practice. Opportunities to use VR visualisation tools and exposure to positive use cases at workplaces are essential to moderate the perceived efforts for VR adoption and encourage further integration. Results also show stakeholders' opinions towards VR visualisation tools affect both determinants. The costs of building and maintaining fast-evolving VR systems and facilities still need to be decreased and better justified. In addition to improving the accessibility and affordability of VR visualisation tools, beginner-level training, advertising on VR's design capabilities, and accessible learning resources should be considered to enhance designers' perceived efforts, necessity, and industry friendliness of VR integration.

The paper concludes with key benefits, considerations, and recommendations for adopting VR visualisation tools in practice, offering guidance for further VR integration in industrial design. Some limitations in this study are acknowledged. Increased sample size and diversity would further validate the findings. Further work may embody alternative research methods to enrich the insights on designers' performance and effort expectancy, i.e., observations of trial and ongoing use of VR visualisation tools.

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