# Industry 4.0 Design Reviews: A Conceptual Virtual Reality Interface


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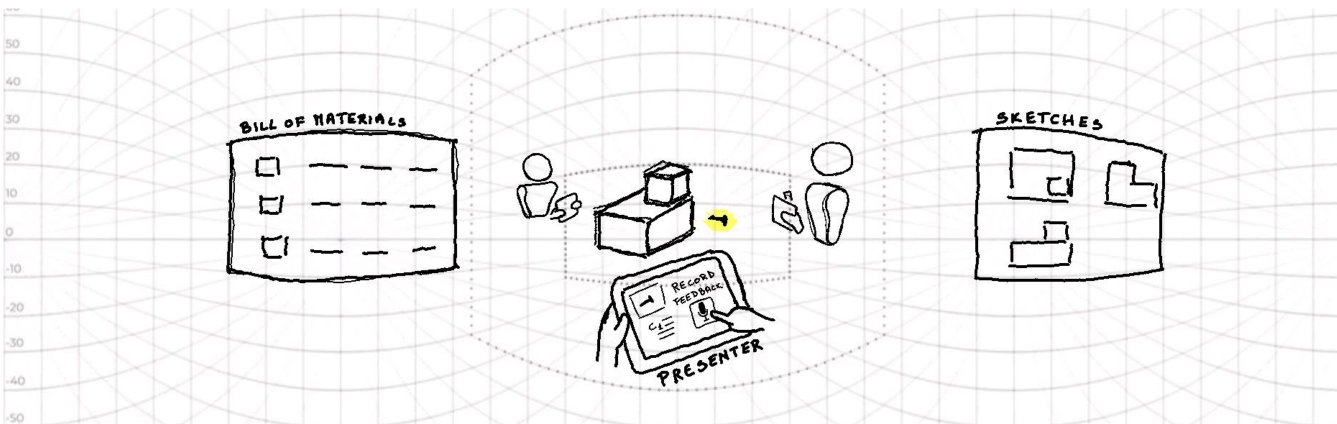


Figure 1: Low fidelity prototype developed on Kurbatov's equirectangular grid [29], 360 interactive version: https://xr.


## ABSTRACT

Computer-aided design (CAD) and 3D models have become the state-of-the-art tools for visual communication, moving beyond traditional 2D line-drawings. Recently, visual communication provided by CAD and 3D models has been further enhanced by contextualization, immersion, and presence induced by virtual reality (VR), allowing engineers, clients, and stakeholders to collaborate in a shared virtual space and use natural interactions to manipulate the CAD and 3D models. However, literature shows that the adoption of VR technologies is still low amongst engineering teams, mainly due to a lack of expertise in how to integrate and use VR in existing design and development workflows, in particular for design views, a key process during product design and development. In this paper, a qualitative user study that aims to understand the pain point of adopting VR in design reviews by engineering teams is presented. The study highlighted that the main factor contributing to low adoption is due to the difficulty in updating and producing the required design review documentation within VR. In response to this finding, a concept design of embedded documentation management system VR interface for VR design reviews was developed in the form of a paper prototype. The prototype was developed from the outputs of a design workshop with potential users, which enables users to create, update, and manage design review documentation. The findings from the qualitative user study and the concept design constitute the original contribution to knowledge for this paper.

## CCS CONCEPTS

• Human-centered computing → Treemaps; Visualization design and evaluation methods.

## KEYWORDS

Human-centered Visualization, neural networks, gaze detection, text tagging

## 1 INTRODUCTION

Virtual Reality (VR) has the potential to innovate and enhance design and development workflows, providing the ability for immersive collaboration between engineers, clients and stakeholders from anywhere in the world [19]. Although adoption of VR technologies in engineering is slowly improving [25], engineers still struggle to embrace VR due to lack of tools that allow direct access to business information and integration within their workflows [4].

A crucial part of the engineering design and development workflow is the design review [28]. Design reviews are milestone events which are frequently held during the design of a new product to ensure the design meets the client and stakeholder requirements [31]. These review sessions are a key stage in the progression of the design of a product, and involve clients, engineers, and stakeholders to discuss the current state of a product design, validate such design against previously identified design requirements and specifications [20], and get joint approval on the design to move onto the next stage of the product development or manufacturing.

The potential of using VR during design reviews has been highlighted by Wolfartsberger et al. [32] and, in recent years, several authors have explored the introduction of VR technology within the design review tasks and activities [5, 19, 26], providing engineers, stakeholders and clients immersive visualisations of 3D model designs. Enterprise solutions with VR interaction packages, such as Theorem XR [21], Virtalis Reach [22], ShapesXR [17], and Arkio [12], are also entering maturity within the industry, offering accessible solutions for engineers to easily bring a 3D CAD model into virtual reality environments [32]. Despite the research and enterprise efforts, VR design reviews are yet to be widely adopted by engineering and design teams [4, 25], as such this paper focuses on the obstacles that are preventing engineers to adopt VR for design reviews.

This paper contributes to knowledge by presenting findings from a qualitative study aimed to understand barriers to adoption of VR in design reviews, as well as a concept design, in the form of paper prototypes, for solutions to the pain points identified during the study.

## 2 RELATED WORK

The awareness of virtual reality (VR) technology within engineering and manufacturing organisations has been increasing year-on-year [25], with the technologies profile further raised by the COVID19 pandemic [4]. However, the overall adoption rate of the technology is still low, with most organisations not using VR technology at all [4, 25]. There are many reasons for the current low adoption rates of VR technology within Architecture, Engineering and Construction (AEC), such as the associated costs, development and learning time, management culture, workflow distribution, and integration of the technology with existing systems [4, 7]. Although adoption rates are currently low, 70% of experts within the AEC industry expect most, if not all, future projects to make use of the technology [4]. Noghabaei et al. [25] estimate that current skill-shortages from design-teams are one of the primary limiting factors of present adoption.

Current adoption of VR technology within AEC organisations has been driven by the ability to enhance their visualisation offerings for engineering and manufacturing. The immersive potential of VR provides engineers, stakeholders and clients, the ability to remotely visualise and interact with virtual 3D products in immersive environments [4]. These features benefit both the organisation, and its customers, complementing rapid prototyping [1] and avoiding travel to on-site locations [4]. Furthermore, these visualisation experiences provide a sense of presence and scale for 3D models, which improves the ability to identify errors [4, 19]. The success of VR as a visualisation tool has lead to research and industry efforts in integrating VR technology within design reviews[5, 19, 26, 32].

### 2.1 Design Reviews

A design review is a periodic and planned activity undertaken during the design process that helps ensure that the design is meeting the project's requirements and specifications [19]. Freeman, Salmon, and Coburn [13] define the engineering design review as a formal process through which the designer can plan and evaluate the design. It involves a collaboration of a variety of stakeholders with the aim of ensuring that the client's needs are met [31]. The client, who might be represented by a company or individuals, has the opportunity to provide a direction of the design during the design review [30].

Design reviews are performed at different stages of design and development process, to ensure compliance with previously defined requirements and to identify and address potential deviations from them at early stages of the project. British Standard [28] defines design reviews as advisory activity which supports verification of product requirements and areas where product or process could be improved. The stages where design reviews are performed are decided during the planning phase which are influenced by number of factors - customer requirements, regulatory requirements, complexity of product, the use of product and consequences of failure. Example design review stages are, input design review, conceptual design review, detail design review and final design review [16]. As such, design reviews enhance the quality assessment in product engineering, particularly those using collaborative software approaches [5]. Three key elements of the design are scrutinised during a design review [9]: whether the outcomes meet the requirements;

shortcomings in the design; and design documents, such as review meeting minutes that show who attended, previous issues, and design choices undertaken in previous iterations of the design.

## 2.2 Virtual Reality

Virtual Reality (VR) is increasingly being considered as a potential solution to enhance design review experiences [31].

Jerald [18] defines VR as a computer-generated 3D environment that can be interacted with and experienced as if it were real.

VR is high-presence medium [18] with potential to fully engage clients by exploiting user immersion and presence [6]. Headmounted displays (HMD) provide a visual access to the 3D environment tracking the position and orientation of the user providing a first person point of view on the virtual environment. Controllers, or alternatively hands and gestures tracking, are used for navigation an manipulation of digital elements within the virtual world
[11].

Embedded within design reviews, VR offers the ability for users to be immersed within a virtual environment to inspect and visualise 3D models, providing access to review and interact with a product design [32].

## 2.3 Documentation management of design review in VR

Existing research has identified the importance of exporting meaningful data from a design review meetings [14], however, with some exceptions [26], most VR design review solutions fail to access, modify, or export data in a meaningful way.

There are a number of commercial VR solutions for performing design reviews in VR. For example, Theorem XR [21] is an enterprise platform that providers users with the ability to import CAD models and host real-time collaborative design reviews sessions remotely. Theroem XR includes basic documentation features, such as the ability to capture view-port screenshots, add comments, and record speech. This data is then collated at the end of the design review session and exported to a pdf document, allowing the information to be easily shared between attendees. However, the data lacks the necessary depth and structure required by engineers.

Shapes XR [17], is a virtual rapid prototyping tool generally used for low-fidelity prototyping, story-boarding and visualization. Shapes XR was found to be useful to populate a virtual environment with key artefacts from the application itself and through the importation of external files. The environment is collaborative allowing multiple users to interact with the design and environment and discuss design changes or elicit further requirements. Functionalities to embed text or data to a single part of the model and exporting data to CAD software are not available. However, the interaction with objects and the inputting and locating of text fields within the environment is highly intuitive.

Arkio [12], is an multi-platform prototyping tool aimed for architects, but also used by engineers to collaboratively discuss designs. The tool allows to edit 3D models at vertex, edge, and face level, as well as assign materials to them. Boolean tools are naturally embedded within the creation of objects allowing complex shapes to be generated quickly and efficiently. Arkio integrates with some of the major modeling tools used in architecture, such as Revit, Rhino, and Sketchup, and allows to import and export BIM data and OBJ files. However there are limited functionalities in terms of documenting changes, which can only be recorded within the environment through post-it notes attached to the 3D model.

Gebert et al. [14] highlighted the need for recording of events during design reviews in VR to strategically incorporate the user's perception of the design into a structured report. Moreover, Gebert et al. [14] proposed a recording method in which events related to the user, product and environment would be processed and stored. A report is subsequently generated allowing events to be filtered. Another method of logging information was developed by Adwernat, Wolf and Gerhard [5] which allowed direct attachment of feedback to specific parts comprising the 3D model. Text messages could be accessed and inputted by selecting icons on a user interface. Information related to the geometry could also be captured via voice recordings.

An alternative solution for capturing data within VR environments is Virtual Observation (VO) [15]. VO is a recording tool for VR simulations which automatically records all user input, simulation data, and events in a format which enables the simulation experience to be consistently reconstructed from any point of recording [15]. This reconstruction can be used for replaying design review sessions to revisit discussions and track interactions, and monitor engagement. However, VO does not provide any documentation capabilities [15]. As such, VO would only be useful as a backup solution for recording design review meetings for archival purposes.

These existing solutions do not provide provide a satisfactory solution for embedding documentation data in a format that can be imported, accessed, and then exported from VR in a meaningful way. As such, current VR design review solutions are unable to utilise the potential of the virtual medium, hindering VR's integration with existing documentation workflows.

Unlike existing works discussed, Sivanathan et al.'s Virtual Aided Design Engineering Review (VADER) [26], solves these issues, offering a real-time multi-modal recording framework for design reviews. VADER provides an in-depth solution for capturing and documenting data within design reviews, featuring the ability to encapsulate data using the 3D model hierarchical structure to embed detailed comments, actions, annotations, flags and attachments to individual parts of the 3D model [26]. The embedded data can then be used to automatically generate a content rich design review report which includes a view of the model, tag searches, timeline view, multi-modal playback and multi-modal search features [26].

However, VADER is designed only for 2D monitors and CAVE systems. By creating a VR interface to integrate the VADER system within HMD based VR environments, engineers can interact naturally with with the 3D model, which was an identified criticism of the existing system [26] and utilise the potential of immersive VR within design reviews. This paper aims to build upon VADER by providing a concept design for a VR interface to the system.

## 3 METHODOLOGY

To understand the pain points of VR adoption within for design reviews a qualitative approach was taken, consisting of a qualitative study composed by semi-structured interviews followed by two workshops, which were conducted after obtaining ethical approval from the university ethics board.

The semi-structured interviews involved five engineers at a manufacturing institute. During the semi-structured interviews, questions related to how design reviews are conducted in practice, the current engineers experience with VR, understanding and adoption of VR by the engineer, and what would the engineer consider to be important features for a VR design review application. The aim of the semi-structured interviews was to understand the problems of adoption of VR in design reviews and how they could be overcome.

The two workshops aimed at understanding how documentation could be accessed in VR, and what features are the most important for VR adoption, respectively. The workshops involved eight participants each, four participants from the same manufacturing institute as the interviews, and four participants from a company, only one participant from the interview also took part in the workshops.

Participants had an average of 18.4 years experience working within the field of product design, with most skilled participant having 30 years, and least skilled with 7 years. The sample size was determined following Malterud et al.'s [23] concept of "information power", which was evaluated by the aim of the study, sample specificity, use of established theory and quality of dialogue. Given the wealth of experience offered by the recruited participants and the targeted aim and approach of the interview structure, five participants was judged to be sufficient for the contextual study. Each participant participated in an hour long semi-structured interview session using Microsoft Teams.

Thematic analysis was performed to analyse the data collected during the semi-structured interviews following the process described by Braun and Clarke [8]. After familiarization with the transcripts, initial codes were created and grouped into themes, with initial themes generated by the first-author of this paper. The initial themes were then independently reviewed by the second and third authors of this paper, following subsequent discussions between the first, second and third authors, the finial themes were agreed and thematic maps generated.

The workshop data was also analysed by the first, second, and third authors of this paper and a group consensus approach was taken to agree on the meaning of the data.

Artefacts developed by participants during one of the workshops to illustrate different ideas about how VR could be used for design reviews were analysed for similarities and functionalities by the listed authors independently, which then used the outputs to produce the paper prototype for the VR interface presented in this paper, taking an artefact-based approach [2]. To avoid bias, the last author was not involved in the interviews or workshops.

## 4 RESULTS

### 4.1 Interviews

The thematic analysis [8] of the semi-structured interviews identified two themes: challenges and concerns and design review improvements, which will be discussed in this section.

*4.1.1 Challenges and Concerns Theme.* The challenges and concerns theme (see Figure 2) highlights the issues faced by engineers during design reviews. This theme is composed by six sub themes: disorganised documentation, too much information, favour routines, sign off delays, in-person, and remote. The 'in-person' and 'remote' themes further divide in three sub themes each. Participants in the interviews repeatedly observed that documentation is often disorganised causing confusion and difficulties in finding relevant information across linked documents and sketches, as highlighted by Participant 3, this formed the 'disorganised documentation' theme.

> *"Opening project folders and jumping forward. Document, after document, after document, sometimes it can be a bit of a pain." (Participant 3)*

The amount of information involved in the design review was also raised as a concern ('too much information' theme) and participants expressed concern in getting overwhelmed during the VR design review by an excessive amount of information being presented in the VR environment. Another concern was the tendency of preferring to use familiar tools that have been tested over the years instead of learning new tools that may improve the process but present an initial risk ('Favour routine' theme), this is true also for the tools they already use as Participant 1 highlights when talking about software they use regularly.

> *"I've never played about with a lot of these [features]. A lot of the problem with these things for me is that they're not kind of easily accessible." (Participant 1)*

Delays in signing off documentation was also raised as a concern.

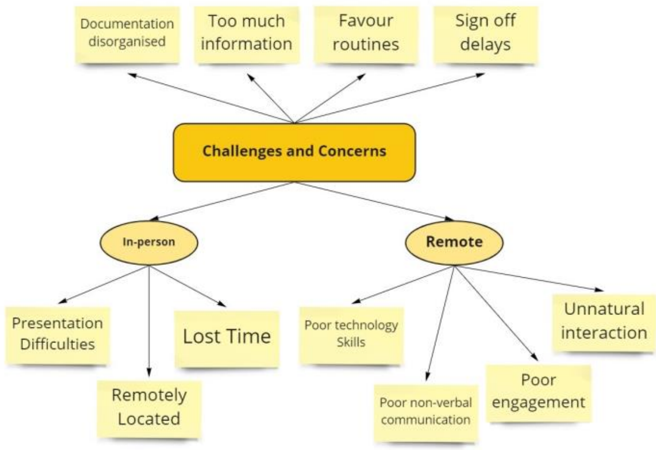


Figure 2: Themes, sub-themes and sub-sub-themes for challenges and concerns.

While engineers explained that design reviews follow the same overall structure ’in-person’ and in ’remote’, the method of presenting the sessions and communicating information was described as different due to the change in the delivery format. For the ’inperson’ theme it was highlighted that the audience who attend design review sessions are often more engaged due to their close proximity to the presentation. However, participants noted that it is difficult to leverage the 3D models during in-person design reviews as the content is often restricted to a single computer screen (’presentation difficulties’ theme). Furthermore,attendees are located a significant distance from the hosting facility (’remotely located’ and ’lost time’ themes), making it difficult for all stakeholders and experts to attend as highlighted by participant 4:

> *"More often than not, the customers not based in Glasgow... so people outside of Scotland, having them come [for short sessions or small projects], it’s just not really feasible." (Participant 4)*

The ’remote’ theme highlights that while remote sessions allow to better leverage 3D visualisations of data, not all attendees find the technology accessible:

> *"The biggest thing to factor in all this is that some people are just not at all comfortable with tech in any way shape or form." (Participant 1)*

A big concern with remote design review is the lack of participation, which are not always caused by accessibility issues. Often, engineers and stakeholders are prone to dialing-in to the sessions, and split their attention between the design review and other activities:

> *"More often than not... a couple people providing a lot of input and then all the other people were just kind of dialing in... [as they are often focused on other work deadlines]." (Participant 4)*

It was also noted in the interviews that non-verbal communication in remote design review is lacking and interaction is not natural.

These are important elements to consider when envisioning a VR design review system. Although the use of VR HMD likely improve attendees attention, due to their limited ability to work on external projects while wearing an HMD, and improve non verbal communication through avatars’ body movements, the involvement of HMDs also introduce accessibility concerns, especially for those that are reluctant to learn new tools or have poor technology skills. As such, it is important that engineers consider the suitability of using VR for design reviews when engaging with non-technologically skilled clients or stakeholders.

*4.1.2 Design Review Improvements.* The design review improvements theme (see Figure 3) identifies the features and tools required by engineers to leverage the advantage of virtual reality to improve the hosting and delivery of design reviews. This theme is composed of three sub-themes: Experience, Visualization, and with additional sub-sub-themes which focus on specific features requested for a virtual reality solution.

Engineers desire to use VR is often driven by its ability to enhance the design review experience. One of the primary drivers of VR immersive environments is the ability of avatars to provide copresence and group cohesion in remote collaborations, which is missing with current non-VR solutions such as Teams or Zoom. VR offers the ability to create a safe immersive environment for attendees, allowing engineers, stakeholders and clients to be able to challenge designs while maintaining the group experience, as noted by participant 1:

> *"you want to create a a scenario where people feel comfortable. So what you’re talking about the the the possibility to challenge your design if necessary and because if you overwhelm with information they don’t necessarily have the opportunity to do that and you can end up getting that design approval without having a properly robust review." (Participant 1)*

By using VR to perform design reviews, participants highlighted the advantages offered by VR, allowing clients and stakeholders

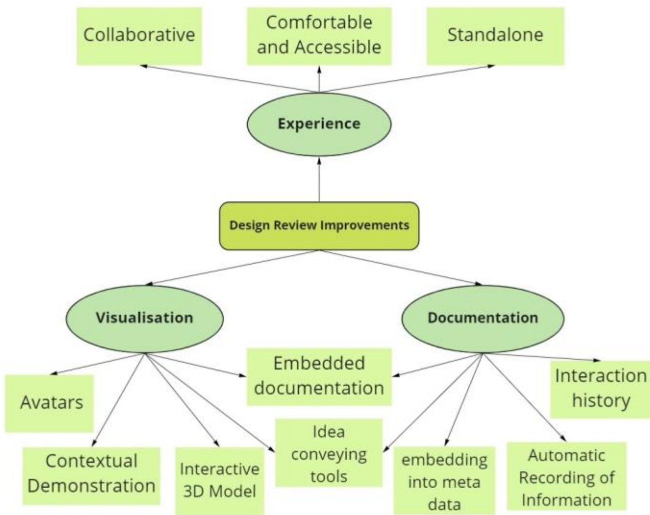


Figure 3: Themes, sub-themes and sub-sub-themes for potential improvements to the design review process for VR.

with the ability to visualise and interact with a virtual 3D model to enhance the capabilities of design reviews:

> *"You can visualize the 3D model in front of you, do sectional cuts and spin it round and things [you can not do at the moment]." (Participant 5)*

These capabilities allow engineers to share their experience with clients and stakeholders, providing an immersive opportunity to showcase the design in a format that accessible to non-skilled attendees. Immersive environments are also perceived to provide the opportunity for engineers to create a virtual walk-through of a product within contextual environment. Engineers also expressed the desire to contextualize the design review by 3D scanning the environments where the product will be located, then host the design review session within the scanned environments.

The 'embedded documentation' theme captures participants concerns with accessing required material within VR design reviews. As discussed by Participant 3, engineers required the ability to embed documentation material directly to 3D models so all data can be accessed and modified within VR from a central source of truth:

> *"[I would want to] embed documents and stuff... So you can have all the documentation, then you can say 'Here you can [access and review] all my reference material' as we're talking." (Participant 3)*

By embedding documentation material directly to individual parts of a 3D model, participants believed they would be able to effectively convey and present information more intelligently to audiences within a VR environment compared to traditional documentation processes which are currently used. Furthermore, by embedding documentation data directly to individual parts of a 3D model, engineers could use the 3D model throughout the product design process to record and access all necessary information from a single location:

> *"When moving towards [VR solutions] like a model based systems approach to your design, you need to then find the way to smartly and intelligently capture all the information that's relevant to your design and not using [traditional] documents, but by using things like metadata and information attached to the [3D] model." (Participant 1)*

By embedding documentation to the 3D model, engineers could interact directly with the individual parts to access the relevant information, documentation, and specifications. This allows to provide attendees with the ability to quickly access only the relevant information for part of a 3D model, avoiding the concern for overwhelming clients and stakeholders:

> *"Have a 3D model so could have areas circled and a line that runs off and points to the particular document that's relevant to that bit of the model." (Participant 1)*

Because the interviews relied only on the information acquired from five semi-structured interviews with experts, it was deemed necessary to validate the findings to ensure that Malterud et al.'s [23] concept of "information power" was satisfactory applied during the data collection and analysis of the resultant themes.

## 4.2 Workshops

To validate the findings from the interviews, two interactive workshops were conducted with different participants from the manufacturing institute and participants form a company. The first workshop aimed to identify which tools and features are considered most valuable for engineers performing design reviews in VR. The second workshop aimed to let participants to generate their vision on what features an embedded documentation system in a VR design review would be and iterate upon ideas of other participants. Both of these workshops were hosted remotely using Microsoft Teams [10] and Miro [24].

*4.2.1 Features importance workshop.* The features importance workshop was based on an 'investment' activity. Each participant was given fictional money for an amount of £100 and asked to invest the money as they saw fit between 15 different features for VR design reviews. VR features were selected from the thematic maps discussed in Section 4, enterprise solutions [12, 17, 21] and exiting research [5, 19, 32]. Participants were informed they could diversify their investment as much, or as little as possible, however, the ultimate objective was for participants to select the features they believed would provide the most benefit to engineers using VR to perform design reviews.

The workshop validated the findings from the thematic maps, reinforcing the identified themes were representative of engineers requirements for using VR to perform design reviews. The top five features invested in by participants during the workshop replicated the findings discovered from the thematic analysis, highlighting the embedded documentation gap present in existing solutions. The top five features were:

(1) Embedded documentation within the 3D model
(2) Interactive tools for the 3D Model
(3) Access history of design changes
(4) Demonstration within contextual environment
(5) Ability to assemble and dismantle model

Furthermore, the workshop verified that the chosen research direction to focus on embedded documentation within 3D models was correct, as 7 of the 8 participants opted to invest in the feature. To understand why participants put significant emphasis on the embedded documentation feature, participants were asked to explain and justify their investment choice.

The *embedded documentation feature* was universally viewed as important by participants as it offered a centralised solution for capturing and storing data, providing a single source of truth for engineers and stakeholders to verify data and information. By maintaining a single source of truth for data, it would make information easier to access and verify, improving engineers workloads. Furthermore, by combining data directly to individual 3D parts of the model, the combined 3D model and documentation feature could be re-used and supplied to help stakeholders and customers throughout the product design, manufacturing and support life-cycle. It was envisioned that the system could eventually be integrated with CAD software, allowing information captured during the design review session to be accessed within a single interface, avoiding the need jump between multiple applications to see documentation files.

*4.2.2 Ideation workshop.* The ideation workshop was designed to allow participants to generate and iterate upon ideas. Using a combination of drawings and descriptions participants were able to visualise and explain their vision for an embedded documentation system for VR. The workshop was based on a 'Round Robin' activity. In the 'Round Robin' a canvas for each participant was created and arranged in a circle, the canvas was split into four quadrants. Each participant was given 5 minutes to draw and describe their idea on the first quadrant. After the 5 minute timer elapsed, participants were asked to move clockwise to the next canvas and asked study the idea in the first quadrant and build upon it by sketching in the second quadrant of the canvas, the process was then repeated until all four quadrant were filled.

Upon conclusion of the workshop, a total of eight canvases provided eight main ideas and three improvements upon each idea. Analysis of the resulting ideas can be summarised as follows:

(1) Official meeting minutes reports are automatically generated following VR design review sessions based on interactions and engagement with the 3D model (see Figure 4).
(2) Using VR to allow remote experts to attend design review sessions in a format that allows them to effective convey and capture their input.
(3) Logging of data directly to the part or surface of the 3D model, which can be exported outside of the VR session (see Figure 5).
(4) Documentation features which are designed to maximise the advantages offered by AR/VR medium.
(5) A standardised template and structure to create, modify and update documentation within VR sessions that can be used industry-wide and remain associated with relevant parts or sections of a 3D model throughout a products life-cycle.
(6) Implement VR management system to monitor manufacturing readiness level for different parts of the 3D model.
(7) Interact and generate actionable events, notes, and documents to parts of a 3D model during a design review which can be viewed within CAD software.
(8) Automatic linking of documentation data to 3D models which can be accessed and updated during VR design reviews (see Figure 6).

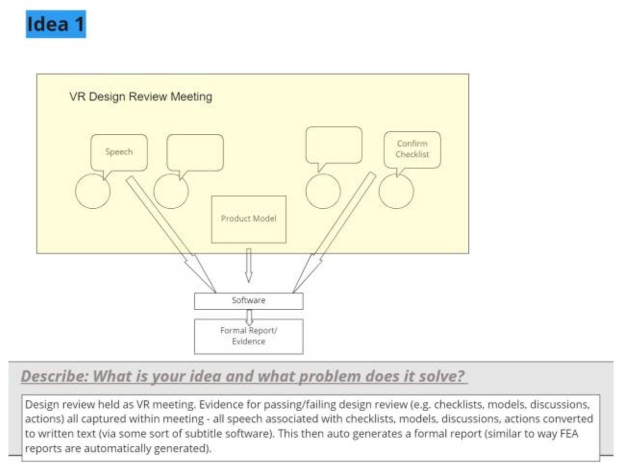


Figure 4: Activity board 1, Idea 1: The automatic generation of design review meeting minutes and milestone report from participant engagement during VR hosted design reviews.

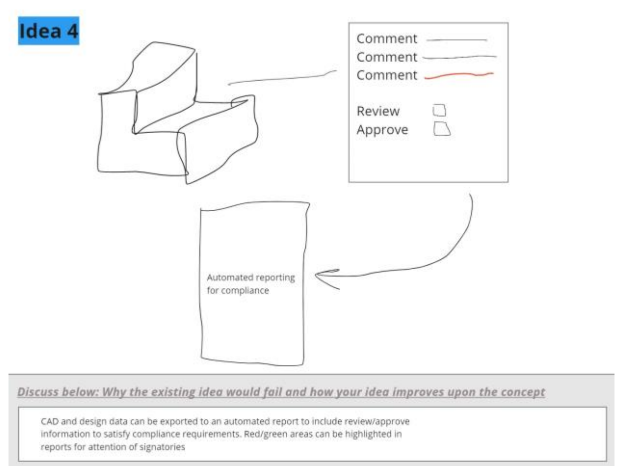

Figure 5: Activity board 3, Idea 4: Data and information being embedded directly to individual parts of a 3D model within a VR environment. The 3D model can then operate as a single source of truth for all design specifications and information.

From these sketches, it is clear that participants ideas follow a common theme, which is the ability to create, access and update data that is directly embedded onto individual parts of the presented 3D model design. This data includes notes, actions, and meeting minutes, which form the core outline of the design review report,

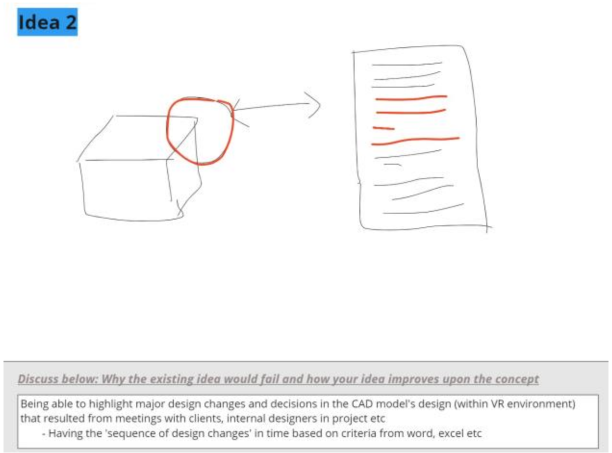


Figure 6: Activity board 8, Idea 2: Ability to embed all design modifications, comments and actions directly onto the 3D model. Participants are then able to access historical changes and documentation material by interacting with individual parts the 3D model. This feature is designed to provide an appealing visualisation to the client of the modifications made and actions taken throughout the design of a product, while acting as a single source of truth for design changes.

and act as a milestone output for what was approved, what actions require attention, and, next steps to be taken. Following these workshop findings, it was decided to develop conceptual designs of participants proposed vision for an embedded documentation system for VR design reviews in the form of paper prototypes that will be further iterated and developed in subsequent work.

## 5 VR INTERFACES DESIGN CONCEPT

The eight ideas and improvements developed in the ideation workshop were analysed for similarities, the analysis resulted in key points regarding the interactions needed for the VR interface. The common theme for all ideas and sketches was the embedding of the information within the three dimensional model with the ability to access the information by selecting different areas or components of the model. Concerns found through the interviews highlight that the information and documentation should be organised logically within the space allowing engineers to see the information they need to present together with the 3D model, whilst at the same time avoid information overload. As such the idea of configurable personal and public space was used as a first step for organising the information in a personalised way. Personal space refers to the area in the proximity of the avatar and it moves rigidly with it, objects in the personal space are only visible and interactable by the avatar to which it belongs. Public space is any area of space that is shared with others, objects in public space are visible and interactable by anyone in the environment.

To make interaction intuitive the concept of diegetic interface [3] was exploited, providing virtual tablets to every participant in the meeting. These tablets are augmented by magic interactions [27] which allow engineers to extract documents and 3D models from the tablet and position them in space through a ’grab and pull’ gesture performed above the surface of the virtual tablet, see figure
7.

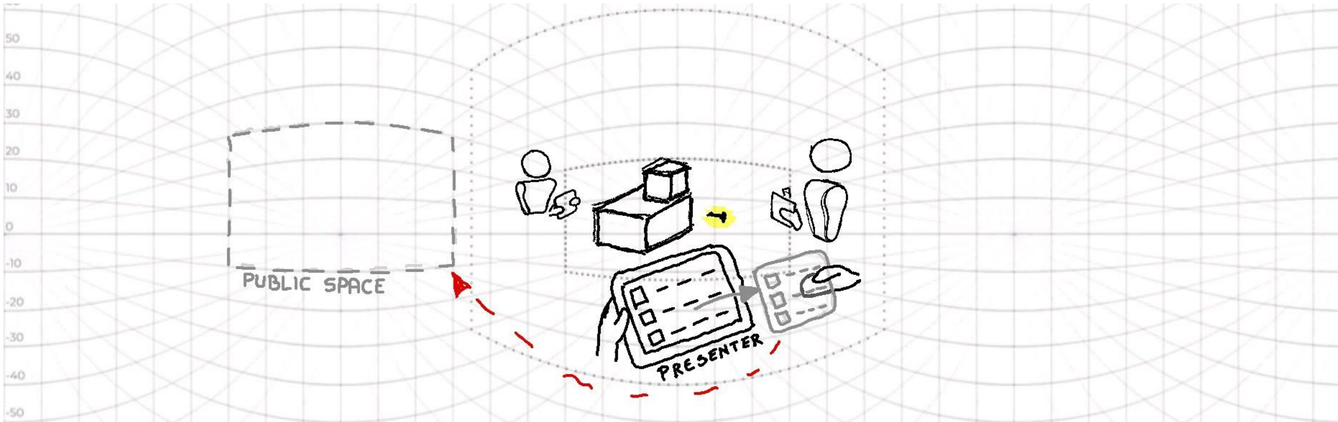


Figure 7: Users can extract information from the tablet and place it in public of private space. 360 version here.

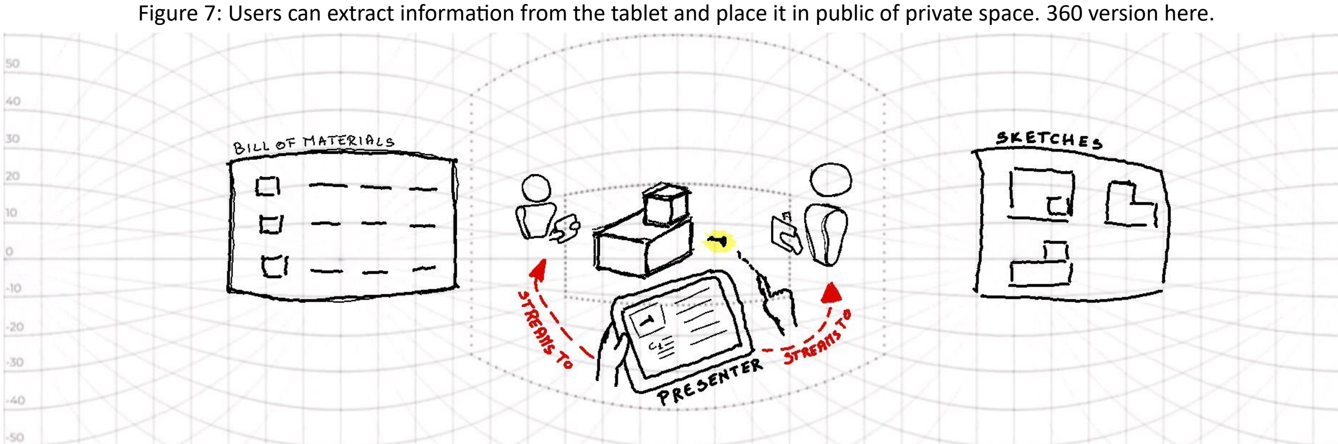


Figure 8: information is attached to part of the 3D model and can be accessed on the tabled by selecting the 3D objects. The information can be shared with others in the space. 360 version here.

Once engineers have configured the public space as they prefer, they can save it and start discussing the design with the stakeholders. Information related to the 3D models is extracted by pointing to part of the model and selecting them, the information displays on the tablet and the presenter can share to the tablet of other participants, see figure 8, which can then extract it and position it in their personal space for consumption or keep it on the tablet, see figure 9. The separation between personal and public space allow each participant to have the information they think is most relevant for the discussion without cluttering the space for everyone, improving organization and reducing information overload. Recording of changes and feedback within the environment is achieved through voice recording, which is later converted to text, see figure 1, sketching is also possible through the tablet and can be shared with other participants again through the tablet or through a board placed in public space, see figure 10.

## 6 CONCLUSION AND FUTURE WORK

A crucial part of the engineering design and development workflow is the design review [28]. The potential for immersive VR to innovate and enhance design reviews within the AEC industry is widely recognised within the literature [19, 25, 32]. However, current enterprise VR solutions [21] which aim to provide an accessible platform for engineers to host design reviews, fail to provide meaningful solutions for importing, modifying or exporting documentation data within these VR sessions. Without this capability, VR solutions do not integrate smoothly with engineers workflows.

This paper proposes the concept of a VR interface design which builds upon Sivanathan et al.’s VADER system [26] to offer embedded documentation features within HMD based VR. Unlike existing solutions [21], this concept meets the needs of engineers and integrates with existing workflows. Furthermore, the conceptual designs of this VR interface is influenced by the ideas and sketches from engineers during the workshop activities, which formed a common theme for utilising the 3D model as an interaction source to access and modify documentation data.

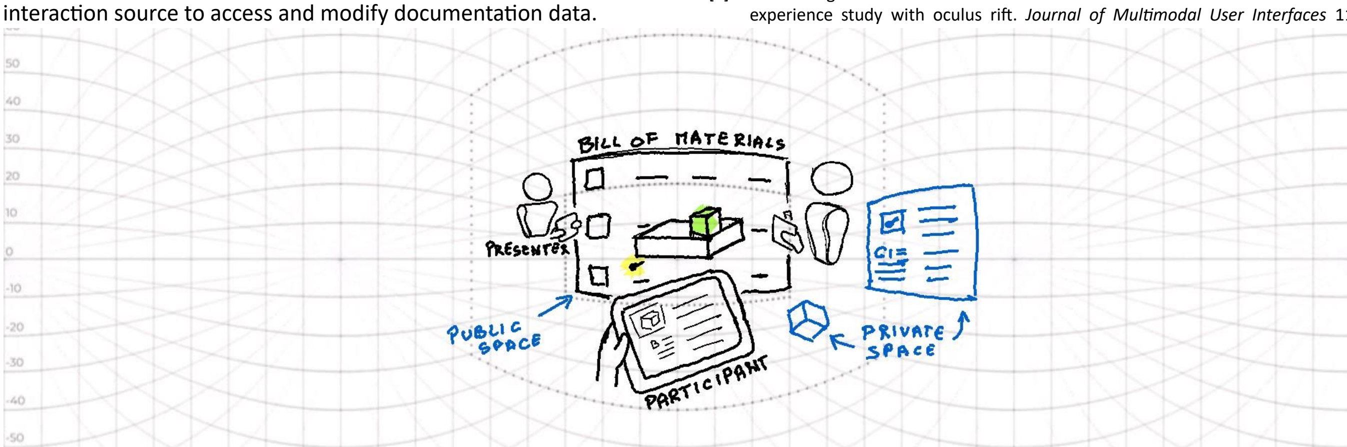


Figure 9: Information and 3D models extracted from tablet and placed on private space. Only the user can see private space. 360 version here.

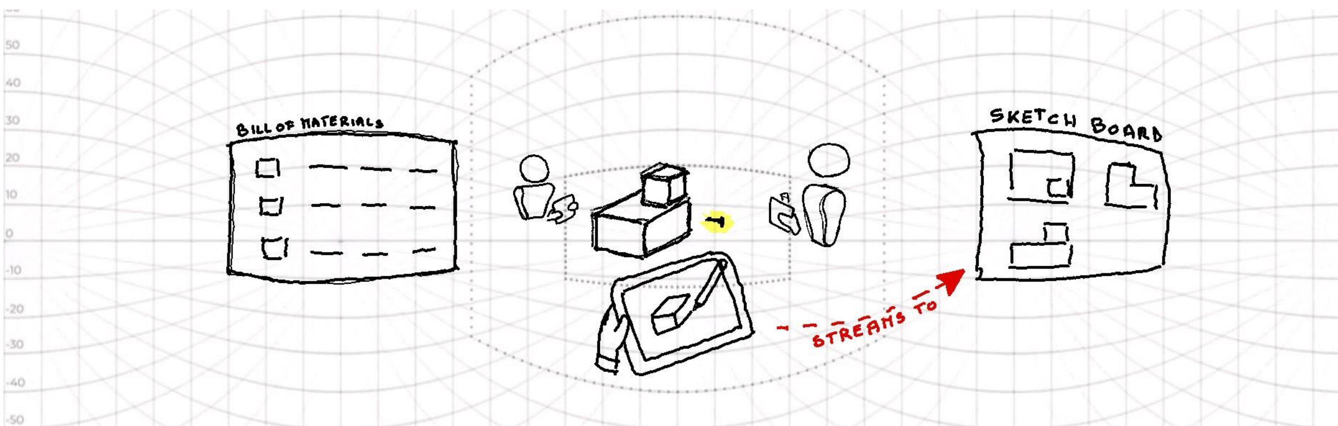


Figure 10: Sketches can also be created and modified from within VR, saved on the document on export, saved in private space, or shared with other users, either via the tabled or public a space board. 360 version here.

We conclude that the documentation management aspects of VR design reviews are lacking within existing enterprise platforms, resulting in VR solutions not meeting the needs of end-users, and failing to achieve the proposed potential for digitally transforming design reviews. It is hoped this paper provides an initial step towards identifying and rectifying this gap.

For future work, the authors aim to iterate upon the concept designs presented in this paper to validate them and develop them into a functional VR prototype that will be validated by engineers.

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