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THE EVALUATION OF A VIRTUAL-AIDED DESIGN ENGINEERING REVIEW (VADER) SYSTEM FOR AUTOMATED KNOWLEDGE CAPTURE AND REUSE

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ABSTRACT

Conducting knowledge capture and embedding it into a products' through lifecycle remains a key issue in engineering industries; particularly with regard to rationale associated knowledge emanating during formal design reviews. Manual, and often interruptive, methods with associated costly overheads, exacerbate the already time consuming process. As well as these disadvantages, manual methods can potentially capture the wrong data due to human error or not fully-capturing all the pertinent information and associated relationships. Consequently, industries are seeking automated engineering knowledge capture and rationale that adds value to product and processes, potentially reaping the benefits of time and cost. Previous work by the authors proved how user-logging in virtual environments aid unobtrusive capture of engineering knowledge and rationale in design tasks.

This paper advances the work further through a Virtual Aided Design Engineering Review (VADER) system developed to automatically and unobtrusively capture both multimodal human-computer and human-human interactivity during design reviews via the synchronous time-phased logging of software interactions, product models, audio, video and input devices. By processing the captured data review reports and records can be automatically generated as well as allowing fast knowledge retrieval. The backbone of VADER is a multimodal device and data fusion architecture to capture and synchronise structured and unstructured data in realtime. Visualisation is through a 3D virtual environment. In addition to allowing engineers to visualise and annotate 3D design models, the system provides a timeline interface to search and visualise the captured decisions from a design review.

The VADER system has been put through its initial industrial trial and reported herein. Objective and subjective analysis indicate the VADER system is intuitive to use and can lead to savings in both time and cost with regard to project reviews.

Keywords: knowledge capture, design review, user logging, time-synchronised capture framework

1. INTRODUCTION

Recent findings [20] reveal that while industries realise the need for and importance of knowledge acquisition, particularly with regard to formal design review meetings, the prevailing factors of time, cost, and organisational structure mean that it is often omitted from the critical path in product lifecycle management (PLM). As a strategic business tool, the body of knowledge within PLM is seldom being utilised effectively, if at all [3, 6]. The contributing factors relates to data (searching, handling, processing, misuse) and reinvention of existing knowledge [3, 18, 26]. This accounts for at least 60% of total operational time [3, 18]. Key findings from the engineering companies interviewed [20] indicated that they:

- want to transcend the importance of knowledge management throughout departments and across the sites
- found that knowledge in the company was difficult to search for
- did not perform manual methods of knowledge capture because of the need to meet deadlines
- were interested with automating the knowledge capture process
- have initiated methods to manually capture knowledge from engineers who are close to retirement

Past challenges in capturing engineering knowledge since the late 80's (see [6, 11, 15, 18, 26]) remain today, as reflected in the findings above. If the process of capturing knowledge in design reviews can be automated this could potentially reduce the time and cost involved [10, 12, 22], which will also encourage more companies to perform knowledge management.

A key factor to the significant overhead involved with traditional methods of knowledge capture is the creation of knowledge bases by hand. This time-consuming and expensive task can also lead to overly-tailored knowledge aimed at a very specific area [14]. Furthermore, one survey has found that knowledge reuse to be almost nonexistent in the companies that were questioned, because the existing methods consisting of notebooks, shared documents and the intranet were found to be lacking [5]. Consequently, companies like NASA have spent many years on its knowledge management strategy in hope to overcome this problem, which has led to numerous tools and frameworks being developed together with a proposed multi-stage 10 year plan [16].

A report commissioned by US Navy shipbuilding to review the best practices and their reuse demonstrates the consequences of not adequately capturing and reusing knowledge during the design process [21]. From the review, it was discovered that the lack of knowledge during the design stage led to redesigns having to be made, which caused the overall project cost to increase 45% in one case and approximately 83% in another.

Many measurable benefits have already been observed through the application of various knowledge management methods in industry. Hall [13] lists the benefits to a frigate manufacturing company:

- Condensed 8,000 procedures for 4 ships to 2,000 class-set of 'SGML records' for 10 ships
- 5 people completely reworked 2,000 routines in around 3,000 person/hours
- Routines delivered for Ship 5 CUT 80%
- Subsequent content deliveries CUT 95%
- Keyboard time for one change CUT more than 50%
- Change cycle time CUT from 1 year to days

Similarly, a survey of small to mid-size enterprises found that the best performing companies were more likely to capture and reuse knowledge related to design, simulation and manufacturing [1]. The reason given for this in the survey is that small and medium enterprises typically have less resources but their product complexity is just as complex, compared with larger companies, so they must find ways to improve their efficiency during the design process.

For the research presented in this paper, 3 engineering companies were visited to discover their existing design review methods, and these were the findings:

- All three companies thought design reviews can be a time-consuming process;
- All three companies relied on manual or semi-automatic capture;
- Only one company utilised virtual reality during the design review process;
- Two companies thought captured information was hard to search for;
- Log books were used by the engineers but the data contained in them were not formally captured;
- None of the design review systems used by the companies have a fully-searchable knowledge store;
- One company would like to see speech recognition and electronic mark-up of drawings in a design review system.

Interestingly, one of the industrial partners – a multinational aerospace company – estimates per design review meetings costs £27,000, and 240 of such meetings annually, any efficacy means to improve the process will bring significant cost savings.

Commercial design review systems are available, yet the experiences of some industrial partners have indicated several key features are missing (that VADER will address). Both Alcove 9 [2] and AVEVA [4] support the visualisation and annotation of CAD models, but do not support audio and video capture, nor do they perform speech recognition or real-time push of context-sensitive information to the engineer. Nvivo [17] supports audio and video capture but has no CAD file format import functionality. These are just examples of bug-bears from industrial users.

Academic research continues to investigate how to improve traditional design review meetings using technology. One paper presents a system for software development design reviews which involves participants using touch-enabled devices for interaction, and Microsoft Kinect trackers are used to track the main presenter in the design review and the members sitting in the audience [7]. However, the presented system does not focus on the capture process of the review meeting and how the data is used afterwards. There has also been a lot of research involving the use of mixed reality systems in design reviews and one such system is presented by Wang & Dunston [25]. Designed for the engineering and construction industry, the system allows design reviews to be held with either co-located users or remote users. The users of the system are required to wear a head-mounted display and can use hand gestures to interact with the virtual models during the design review, but experiments carried out found that the users were experiencing head, neck and arm strain. However, it found that mental workload and task completion time was reduced when using the virtual interface compared to conventional paper-based review meetings. Verlinden *et al* [23] also presents a design review system that uses augmented reality. Known as IAP Design Review, the system can record a review meeting as well as allowing physical prototyping to take place. Users interact with the system using portable devices that have a screen and projector, but the prototype devices were found to be bulky. Audio, video and annotations can be captured, but the replay of the video and audio does not allow the relevant annotations to be viewed simultaneously.

To overcome the shortcomings in existing design review methods, the Virtual Aided Design Review System (VADER) is proposed that automatically and unobtrusively captures multimodal ergo- and egocentric activities during engineering design reviews. Section 2 details the VADER architecture, hardware and software, while Section 3 reports the procedure and user trials conducted. Results and discussion will be presented in Section 4, followed by conclusions in Section 5.

2. VADER OVERVIEW

2.1 Capture Framework

The VADER system consists of a virtual environment that allows engineers to interact with CAD models in a 3D immersive manner. An existing software capture framework – known as Ubiquitous Integration and Synchronisation Architecture (UbiISA) – developed recently by the authors [19] is used to capture and synchronise inputs from multiple data sources in a time-phased manner to allow post-processing to be performed (Figure 1).

Developed using C++ and C#, the capture framework has a unified access interface to enable multiple types of hardware and software inputs to be captured simultaneously, which include the following data types that have already been evaluated by the authors: Siemens NX/PTC Creo log files; bio-physiological signals; eye tracking data; keyboard and mouse inputs; captured video and audio.

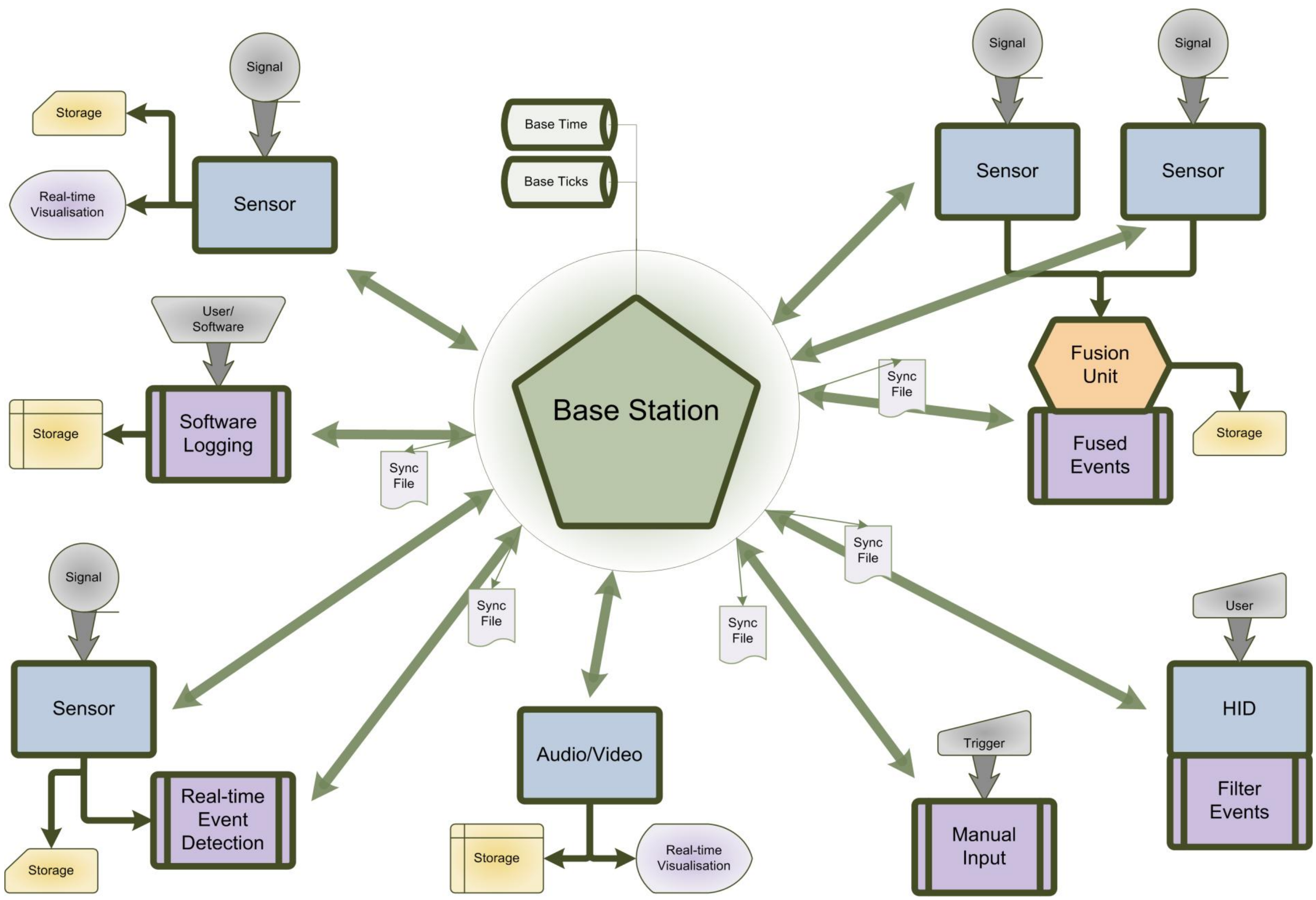

Figure 1 – UbiISA Ubiquitous Data Capture Framework

The current system captures audio, video, keyboard and mouse input, but the modular nature of the capture framework permits extra inputs to be easily added in the future. The ubiquitous nature of the framework allows input devices plugged in and removed from the data capture system in runtime. It consequently forms a data collection environment which runs indefinitely where multiple people with various data logging tools can join and leave the environment when it is necessary. The framework is multiplatform compatible, and in this instance compiled for Linux.

2.2 Apparatus and User Interface

The powerwall 3D projection system consists of a Digital Projection Full-HD resolution stereoscopic projector, 3.2m x 1.8m screen and MacNaughton active shutter glasses worn by the users, as shown in Figure 2. The application is developed on a PC using C++, with the graphics capabilities handled by VTK, an open source 3D graphics toolkit [24]. Two keyboards and mice were used in the setup; one wired set is controlled by the review chairperson while the wireless set is controlled by whoever wants to make a contribution.

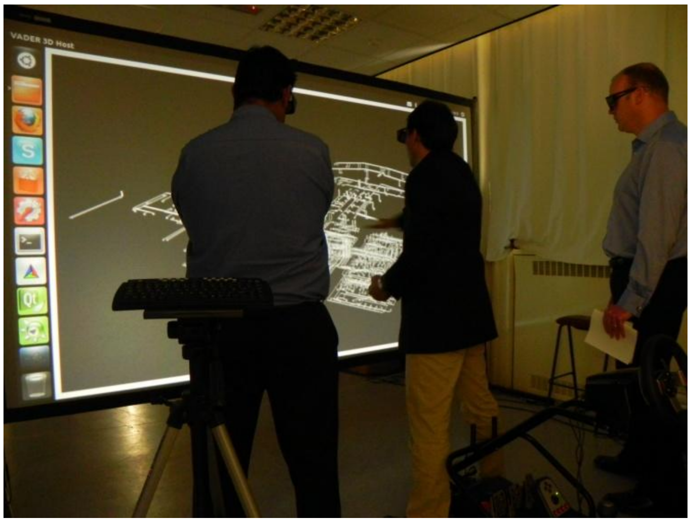

Figure 2 - VADER System in Use

The VADER visualiser supports atypical 3D interaction of CAD models (Figure 3) but crucially, enable annotations to be tagged to specific assemblies, subassemblies or individual components. Both audio and video can be selectively or automatically captured at each design review meeting.

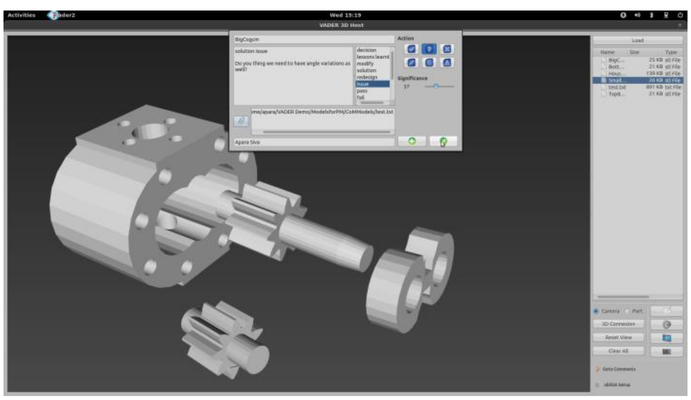

Figure 3 - CAD Assembly Visualisation in VADER

In addition to the traditional visualisation functions such as zoom, rotate and pan, there is also the ability to show and hide specific parts and alter their opacity and colour characteristics.

As illustrated in Figure 4, each annotation will have the part name or number and the engineer's name associated with it, and key flags can be chosen from a list that contains various important issues that are typically found during real-world engineering design reviews. Furthermore, file attachments can be added, and a significance value can be set to represent the importance of the annotation.

The logged annotation data is stored in an XML file format to allow easier post-processing, sharing and reuse. Timestamps generated by the UbiISA framework [19] corresponding to the time when the annotations are created, screenshots, beginning and ending of audio recordings, etc. are stored in binary files with 64 bit Unix time format with an accuracy of a millisecond.

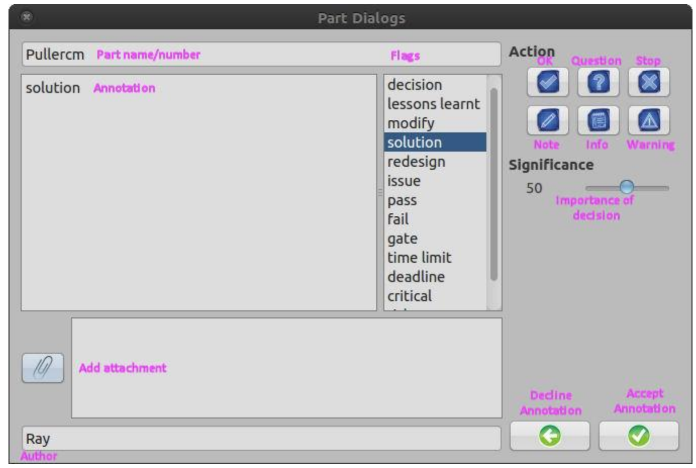

Figure 4 - Annotation Dialogue Box

After the design review has been completed, the captured data can then be visualised in a timeline interface, as shown in Figure 4.

The timeline interface presents a summary of design review in a chronological order, with the ability to search, filter, sort and view all the annotations and audio that has been captured. Furthermore, there is also an option to automatically generate a summary report of design review in an HTML format that contains thumbnail pictures of the CAD model during important points in the meeting.

3. EXPERIMENTAL PROCEDURE

The conducted user trials involved 7 industrial engineers, and involve 4 main stages:

1. A demonstration of the VADER system using a simple CAD assembly model. All the functionality of the system is shown to the participants and they are allowed to ask questions.
2. A previously logged design review meeting involving an assembly model of a scooter is presented to the engineers, who are then asked to analyse the data to understand what happened during the meeting. During this process, the participants will visualise the model, view all the annotations attached to it and listen to the audio that has been captured.
3. Using a more complex assembly model provided by the industrial company, the engineers are tasked with carrying out a mock review of the assembly. The participants will conduct a discussion about the model and what problem areas there are in the current design.

Participants can take turns to use the wireless keyboard and mouse to type in annotations to append to specific components, subassemblies or the whole assembly. The assemblies provided by the 3 companies consisted of a prison building, gyroscopic device subassembly and an optical measurement device subassembly, and all 3 models are real designs used by the companies involved.

4. A questionnaire is filled out to obtain feedback on the usability of the system and how it compares to their current design review methods.

During the mock review carried out in step 3, a video camera is used to film both the engineers and the projection screen, and a microphone is used to capture the discussion as well as verbal annotations that are attached to specific components in the CAD assembly model.

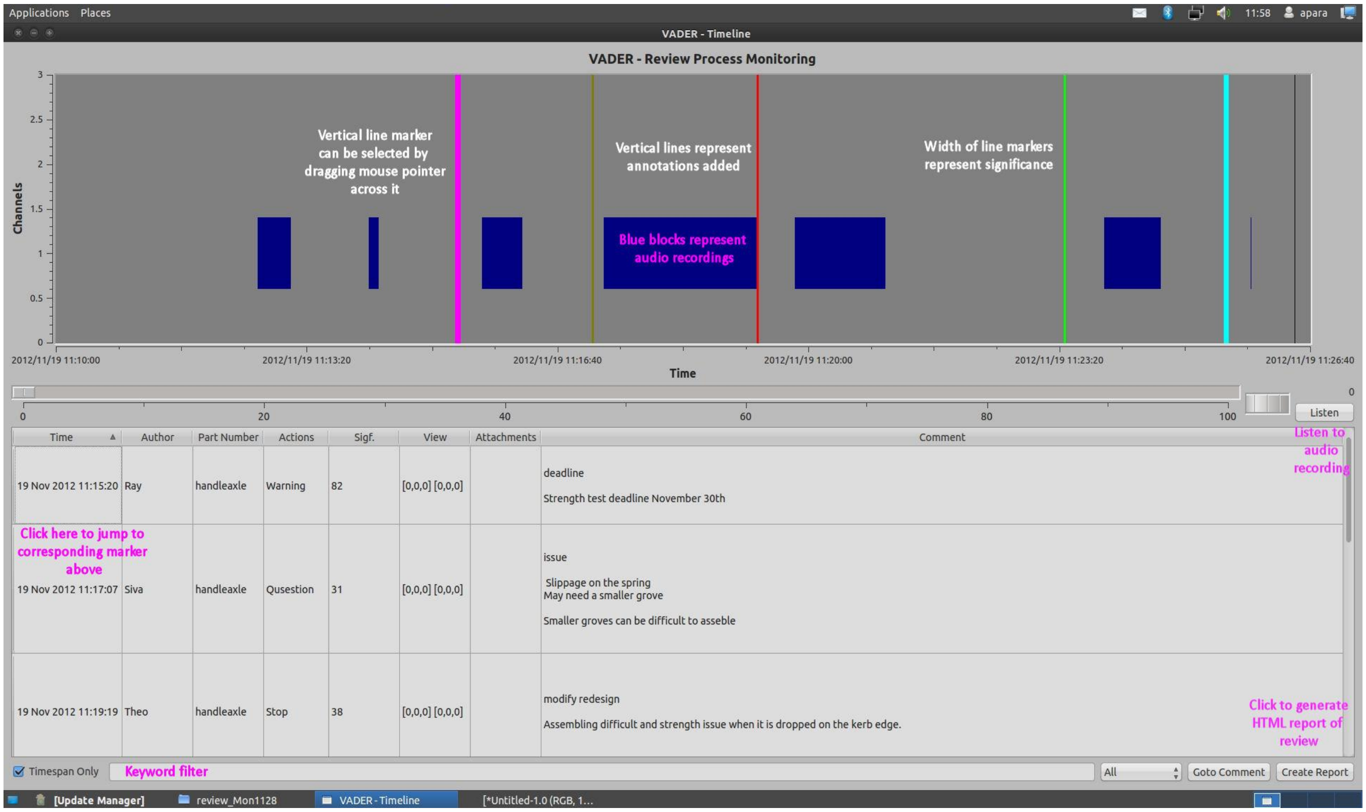

Figure 5 - Timeline Interface for Viewing Design Review Summary

4. RESULTS AND DISCUSSION

The questionnaire uses a System Usability Scale (SUS) [8] to assess the usability and functionality of the VADER system, and the results of this is presented in Graph 1 and Graph 2. The average SUS score out of 100 was calculated to be 59.64 for 7 engineers. Due to a particularly low score of 37.5 from one participant, this contributed to a lower average score. Analysis of the SUS scores indicates that the VADER system was generally found to be quick to learn and simple to use.

Table 1 documents the differences in functionality between VADER and the design review methods employed by the 3 companies, which demonstrates the lack of multimedia capture utilised currently by the companies.

From the comments in the questionnaires, the overall feedback from the engineers was positive, with one of the engineers working for a construction company commenting:

"*Excellent first step and very relevant to our needs. Interested in when it can be used in a real review.*"

One particular aspect that the engineers liked was the ability to automatically generate an HTML summary report of the design review which contains screengrabs of the session. It was mentioned by one engineer that he usually requires up to a day to manually create the minutes and summary of a design review, so being able to automate the process would be very beneficial. Another weakness with traditional design review methods is the difficulty in searching past reviews for information, so the text-based search engine in VADER also received very positive feedback during the user trials.

Future work will focus on improving the user interface of VADER and how users can interact with it. Due to the continually-improving performance and ubiquity of tablet PCs and smartphones, the ability to use these devices to interact with VADER system will be added. This will allow engineers to interact with the CAD model independently from the main design review viewed on the projection screen.

The use of portable devices to interact with VADER also makes it easier to carry out online collaborative design reviews with engineers located at off-site locations. Another improvement to be made will be the addition of speech recognition, which will allow annotations to be added verbally rather than via keyboard input. This functionality was also a suggested improvement by two engineers during the user trial. Speech recognition will also allow a transcription of each design review to be automatically generated, which will be fully-searchable. Finally, the user trials are still on-going, so more engineers will participate in the evaluation of the VADER system, and, most importantly, efficiency comparisons between VADER and traditional design review methods will be carried out.

5. CONCLUSIONS

An engineering design review system called Virtual Aided Design Engineering Review (VADER) has been developed that provides time-phased synchronisation of captured data from engineering design review meetings carried out in a virtual environment, which enables a chronological record of review to be produced.

From the results of the user trials that have been conducted with industrial collaborators, it has demonstrated that the VADER system has received positive feedback on the usability of it, and two aspects that were most liked was the automatic generation of summary reports for the design review and the search engine. Overall, the initial industrial trials have indicated the system's ability to ensure tractability across multimodal sources and data provenance. It is obvious that data security needs to be addressed but is not the remit of this paper.

Future work will concentrate on improving the user interface and add further functionality. This work has proven that the VADER system is generic enough to allow it to be used in other sectors, and links to product and lifecycle systems and other company databases is possible.

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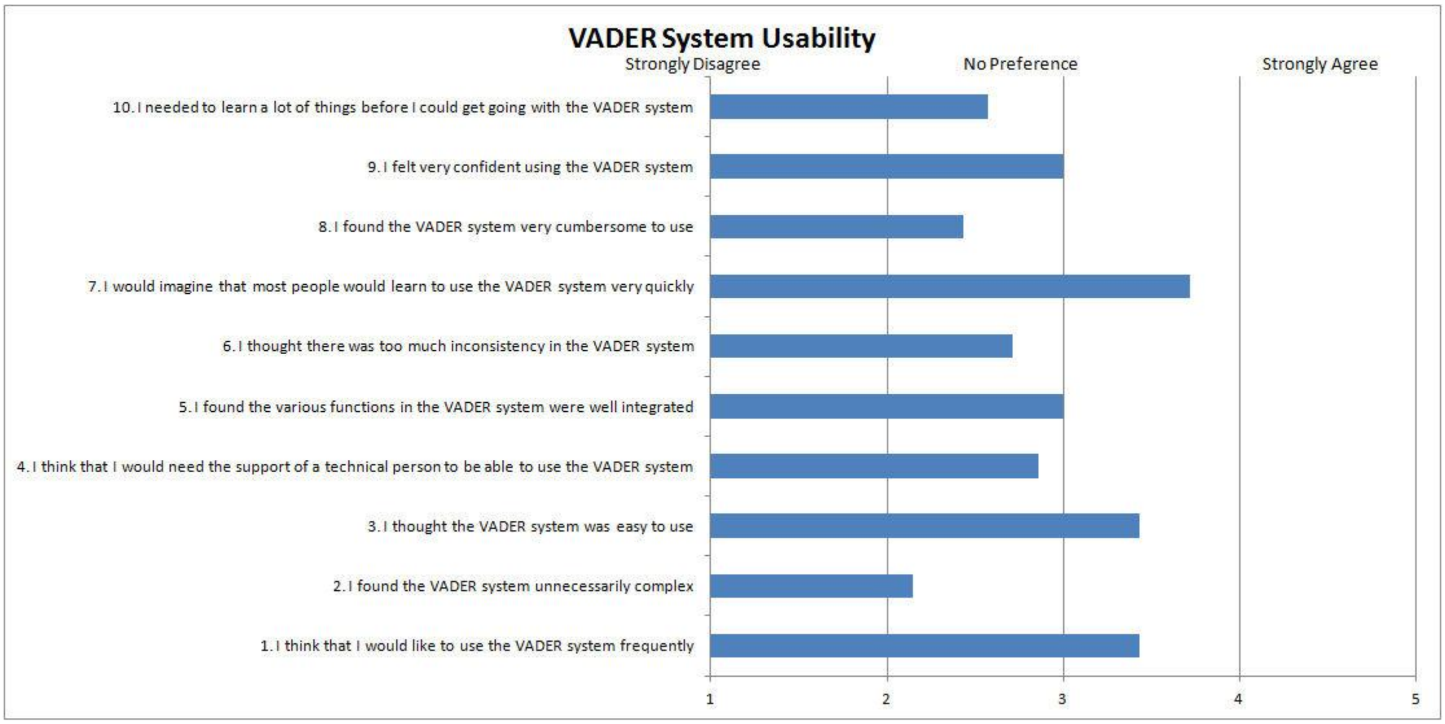
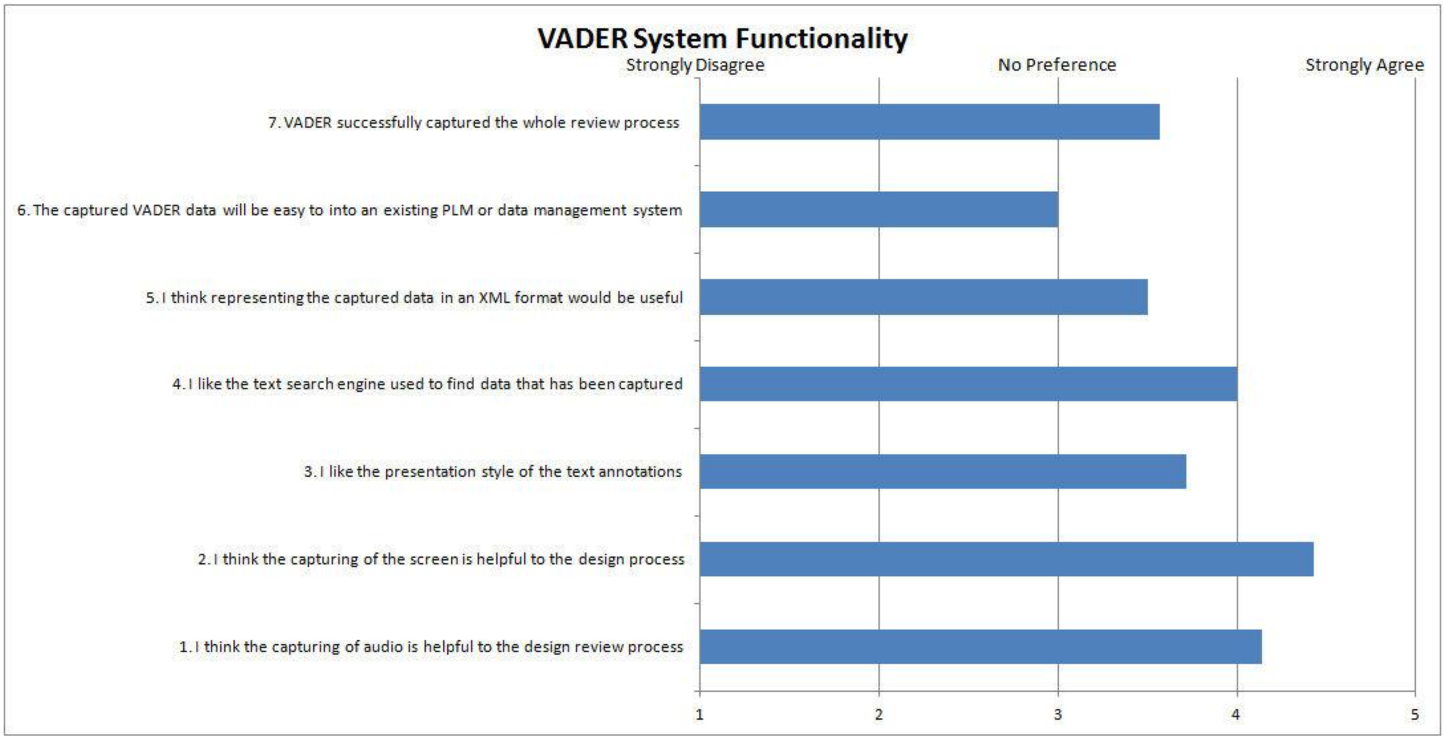


Graph 1 - VADER System Usability



Graph 2 - VADER System Functionality

Table 1 - Design Review Functionality Comparison

Design Review Features	VADER	Company A	Company B	Company C
Annotation of CAD models	✔	✔	✘	✘
Capture and playback of audio	✔	✘	✘	✘
Capture of rendered screen	✔	✔	✘	✘
Search capability for design review related data	✔	✘	✘	✘
3D visualisation of CAD models	✔	✔	✘	✔
Producing design review report/minutes automatically	✔	✘	✘	✘
Support of other input devices (e.g. tablet PCs, smartphones, etc)	✘	✔	✘	✘
Multiple device interaction (e.g. 3D mouse, gesture devices, touch interfaces)	✘	✘	✘	✘
Remote sites running concurrent reviews	✘	✘	✔	✘
Integration with design environment	✘	✔	✘	✘