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MEETING THE REQUIREMENTS FOR SUPPORTING ENGINEERING DESIGN COMMUNICATION - PARTBOOK

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ABSTRACT

The Engineering Design Environment is evolving in many ways. Considerable amounts of data, information and knowledge are 'building up' within engineering companies and engineers are becoming involved in ever-more distributed collaboration activities to tackle complex multi-disciplinary challenges in the design of new products requiring the need to share knowledge. These changes are placing further challenges on Engineering Design Communication (EDC, a fundamental knowledge sharing activity) as the current methods of communication were never specifically designed to support such technical and highly-contextual communication. Much research has been performed on understanding EDC, thus enabling a list of requirements to support EDC to be generated. Therefore, this paper proposes a prescriptive tool, (PartBook) which instantiates these requirements and looks at the next steps being taken to evaluate the tool in meeting the requirements.

Keywords: communication, knowledge management, human behaviour in design, design informatics, PartBook

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1 INTRODUCTION

The modern Engineering Design Environment is evolving to become ever more mobile, globally distributed, multi-disciplinary and collaborative. Table 1 provides an insight into four market leading engineering companies and their total number of products since their incorporation. It is self-evident that there is a build-up of knowledge and expertise that is associated with the development of these products. In addition, these engineering companies have a very well defined family of products often requiring multiple project teams with similar expertise to run concurrently. It follows that to aid decision-making and prevent 'unnecessary' re-occurrence of work, there is a need to improve knowledge sharing between engineering projects and engineers, and ensure reusability knowledge.

Table 1: Product Build-Up (Source: Wikipedia)

Company:	Apple	BMW	Dyson	Airbus
Founded:	1976	1917	1993	1970
Approx No. of Products:	431	83	45	10
Products per Year:	12	0.9	2.4	0.2

Communication remains an intrinsic and critical element of engineering in order to ensure knowledge and information (due to their artefact[1] centered nature (Eckert and Boujut, 2003, Hicks et al., 2008)) is shared between engineers (Perry and Sanderson, 1998, Alavi and Leidner, 2001, Sim and Duffy, 2003). This paper defines communications pertaining to the development of a product as Engineering Design Communication (EDC). The importance of EDC is demonstrated by Tenopir and King's (2004, p.30) review of the communication patterns research within engineering shows that there is a consensus that engineers spend a significant proportion of time conversing about their work, typically in the region of 25-75%. Table 2 provides a summary of key findings.

Table 2: A Brief Summary of the Importance of Communication within Engineering

Study	Summary	Result
Tenopir and King [2004]	A set of surveys conducted from 1958–1998	25–67% of time spent communicating and an average of 47%
Hertzum and Pejtersen [2000]	Case studies using interviews	Engineers spend 40–60% of their work time communicating
Nagle [1998]	Case study	Engineers can spend up to as much as 75% of their time communicating
Ellis and Haugan [1997]	Interviews with industrial experts	Highlights greater use of informal channels as projects progress and engineers make considerable use of both oral and written communication methods.
Zipperer [1993]	Interviews and follow-up questionairre	highlights that engineers consider other engineers as trustworthy sources of information
Handel and Herbsleb [2002]	Analysis of work communications within an instant messenger tool	69% were considered what is colloquially termed *'water-cooler conversations'* as they were an informal and quick exchange of knowledge and information between engineers [Larsson et al., 2002, Herbsleb and Mockus, 2003]
Brown and Duguid [2000]	Studies into communities of practice	Communication used to *'fill in the gaps'* left by formal documentation and process manuals as they can never fully account for every eventuality.
Clarkson and Eckert [2005, p. 20]	Review paper	Informal communications are used by engineers to be kept informed and maintain awareness of project progress.

While the importance of communication is universally accepted, the evolving Engineering Design Environment poses considerable challenges in supporting EDC. One particular challenge concerns the need to use distributed means of communication yet there are a number of challenges in supporting this as the current tools (E-Mail primarily (Delinchant et al., 2002)) are creating a barrier in enabling the same volumes of communications typically seen through Face-to-Face (Eckert et al., 2001). This is due the fact that the current tools lack the richness in terms of contextualising the environment in

[1] An artefact could be a file, documentation, calculation both digital and non-digital, sketch, note and prototype for example

which the communication is being held within when compared to Face-to-Face (Delinchant et al., 2002, Perry and Sanderson, 1998) such as the links between the EDCs and the Engineers and Product Artefact Networks[2]. Current tools also have difficulties in representing multiple perspectives, providing a collaborative communication environment and lack the ability for the *'right'* engineers to be made *'aware'* of communications they could potentially contribute to (Popolov et al., 2000, Schneider et al., 2008). Chiu (2002) summarises the four core challenges in supporting Engineering Design Communication as:

1. Media Used and ensuring that the meaning behind the words is retained.
2. Semantic whereby the right context is projected to the participants.
3. Performance of the communication to generate the right responses, promote a suitable discussion and maintain focus upon the purpose of the communication.
4. Organisational in ensuring that the right engineers are made aware and able to contribute to the communication.

Although there are a number of considerable challenges facing the support of EDC, the potential benefits in improving the support are significant. EDC often contains the rationale behind decisions made and insights/conclusions drawn from the discussion and aggregation of information (Huet et al., 2007) and can be used to describe *'why it is the way it is'* (Regli et al., 2000). Dearden (2006) supports this by describing the idea of *'material utterances'*, which are changes within artefacts (i.e. modifications/changes to documentation) that arise as a result of communication. Engineers can use as much as 70-95% of past designs to develop new products (Eckert et al., 2001, Freund et al., 2005) and thus, being able to understand the reasoning *'why the product documentation is the way it is'* can further aid re-use and reduce the likely occurrence of re-work. This rationale is crucial to ensuring the future relevance of information sources, as it is almost impossible to predict (Eckert et al., 2007).

Ensuring awareness of communications could reduce the time for engineers to receive the information they require to continue with their activities, decrease *'needless'* uncertainty further and increase productivity through supporting engineers' real-time work (Adler, 1995, Daft and Lengel, 1986). Clarkson and Eckert (2005, p.20) discuss how engineers resent the fact that they have to use informal channels to find the information they require, as it is not official company policy and thus, supporting EDC would demonstrate the companies' understanding of the importance of EDC and potentially reduce resentment and encourage greater communication. Further, greater communication has been shown to be indicative of progress being made and successful product development (Liebowitz and Wright, 1999, Griffin and Hauser, 1992).

In order to begin to meet the challenges, this paper looks towards supporting EDC through the development of a Social Media tool known as PartBook. Social Media tools have been defined by Annanperö and Markkula (2010) as "technical solutions that have been designed to help people to communicate". Black et al. (2010) shows that these tools are able to increase the awareness of project progress and have aided teams in reaching and making decisions more quickly. An interview with Mark Zuckerberg[3] sees Social Media tools as the successor to previous formal systems for communication, leading to a more direct and networked means of communication (O'Reilly Media, 2011). This could prevent the need for the engineers to work through a hierarchical structure of personnel before reaching the right engineers (Chiu, 2002). Ploderer et al's (2010) study reveals the positive effect of experts within their respective fields being able to share knowledge to novices and aiding accelerated learning. This could provide benefits in the sharing of knowledge between novice and expert engineers. Thus, it is argued that a Social Media tool has the potential in overcoming the previously discussed challenges in supporting EDC.

PartBook is a Social Media tool that has been developed specifically to meet the requirements Gopsill et al. (2013, In Review) have elicited for supporting EDC through an extensive review of the literature covering the period of 1980-present and summarised within four key areas; EDC and its relationship with the Product Artefact Network, EDC and its relationship with the Engineers' Network, types of EDC and their evolution, and the Engineering context surrounding the EDC. Table 3 presents these requirements. How PartBook instantiates these requirements is discussed, followed by a summary of

[2] Engineers Network: The relationships between the engineers within the company be it hierarchical (i.e. position within a company, seniority), social or task related.
Product Artefact Network: The relationships between the artefacts that define the product be it their position within the companies PLM system or the relations between the artefacts (for example, the tolerance on a part effecting the size of another part).

[3] Founder of FaceBook

how the tool is to be evaluated through three fundamental scenarios in todays Engineering Design Environment.

Table 3: Summary of the Requirements Elicited from Literature (From: Gopsill et al., 2013, In Review)

Requirement No.	Requirement to...
R1	capture the one artefact relating to the purpose of the communication.
R2	capture high–quality representations of the artefact.
R3	enable contributing engineers to support their view by presenting supplementary artefacts limited to one per response.
R4	capture the type of artefact within the representation.
R5	capture the focus upon an artefact.
R6	provide a link to the actual artefact where possible.
R7	allow engineers to push communications to one another.
R8	enable engineers to group communication by tasks.
R9	enable engineers to push communication to experts based upon domain knowledge required.
R10	enable engineers to place personal bookmarking upon communications.
R11	capture the purpose of the EDC.
R12	capture the response types of the engineers contributing to the communications.
R13	permit the appropriate types of response to the communications.
R14	ensure an appropriate limit is placed upon the size of the responses.
R15	enable multiple–threads within a communication.
R16	enable engineers to respond to one or more statement within the communication, thereby enabling divergence/convergence.
R17	capture the type of conclusion for the communication.
R18	enable engineers to refer back to previous communication when making statements.
R19	enable engineers to comment on past communications.
R20	capture the reason for commenting on past communications.
R21	capture the company, product and product lifecycle dimensions of the EDC at creation (where applicable).

2 PARTBOOK – AN INSTANTATION OF THE REQUIREMENTS FOR SUPPORTING ENGINEERING DESIGN COMMUNICATION

PartBook is an open-source Social Media tool that has been developed using HTML5, Javascript, PHP and MySQL. It is both accessible and usable by PC and mobile devices. The features and functionality provided by PartBook are based upon a Social Media Framework, which has been developed by Gopsill et al., (2013, In Review) and comprises of a communication process, an EDC classification matrix and the data and information requirements for each stage in the process. Their work discusses in depth, the suitability and appropriate application of Social Media to support EDC. This paper details the functionality of PartBook with particular focus on the user perspective and communication process within the tool (shown in figure 1). Reference to the requirements (given in table 3) will be made throughout the discussion.

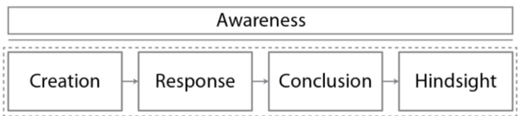

Figure 1: The Communication Process within PartBook

2.1 Creation of a Communication

The creation of a communication within PartBook follows a four step on-screen process (Figure 2). It is a requirement for the engineer to supply an image of the artefact pertaining to the EDC (R1, R2) with the additional provision of enabling the engineer to provide an URL/real-world location of the artefact (R6). This provides engineers with a quick method of accessing the artefact and effecting changes if required. An image provides a temporal snapshot of the artefact at the time the engineer wishes to have the communication. Thus, upon reference in the future, engineers are able to understand the state of the artefact at that time. Step two requires the engineer to provide the type of artefact that pertains to the communication (for example, a CAD file) (R4) and the *'focal'* point (R5) (for example, Error Message). This provides additional contextual information to the communication and enables the aggregation and filtering based upon the type and *'focal'* point. Step three enables the engineer to type their message. There is a 250-character limit to maintain conciseness in comments being made and prevent *'waffle'* (Perry and Sanderson, 1998). As well as typing their message, the engineers are required to determine the type of communication they wish to have (R11) as this will drive the type of responses that participating engineers can make alongside focusing the communication and working towards an outcome. Finally, stage four enables the engineer to align the communication across product, part, concept and lifecycle dimensions to further place the communication in the wider Engineering Design Environments context, thereby enabling search, retrieval and awareness based upon that particular dimension (R21). Clicking 'Create' creates generates the communication within PartBook, which can be responded to by the other engineers.

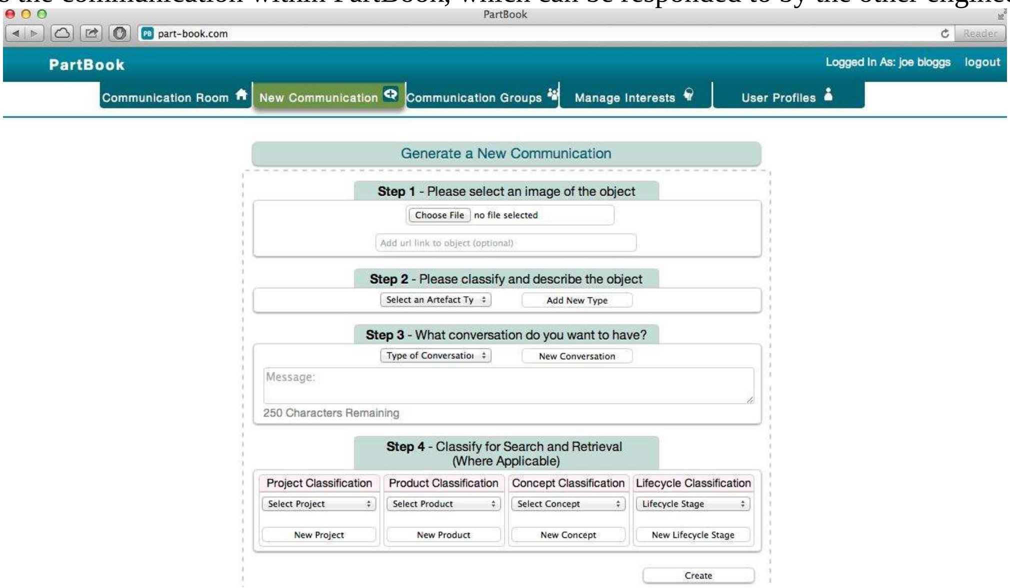

Figure 2: New Communication Screen

2.2 Response(s) to a Communication

Once the EDC has been created, engineers are able to select the communication from their menu and make responses. Figure 3 demonstrates that the communication can be multi-threaded to enable different perspectives to coincide, (R15) which is a key issue in current tools such as E-Mail as it is often difficult to diverge and converge during discussions as they are stored as single threads. Engineers are required to select one or more communication elements to which they are replying to and they are then able to make their response. Again, this is character limited to maintain concise responses and the engineer has to select the type of response they are making (R12) as this aids other participating engineers to understand *'where they are coming from'*. In addition, they are able to provide additional artefacts through the capture of an image, which might for example, show the effect of changes they have made to an artefact (e.g. showing the code that fixes a CAD error). The EDC remains within this state until the originating engineer determines that their EDC has reached its conclusion.

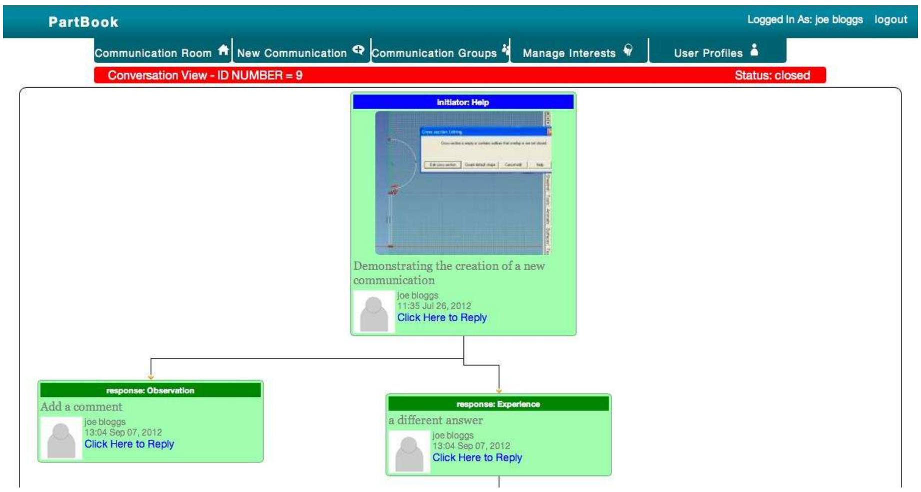

Figure 3: Responding to a Communication

2.3 Conclusion of a Communication

The EDC reaches its conclusion when the originating engineer determines that it has reached that point (Figure 4). This stage requires the engineer to select the type of conclusion that has been reached by the EDC (R17) as well as providing a final comment detailing the result of the EDC. In addition, they are able to provide a final image of the artefact, which can be used to record the consequence of the

EDC on the artefact (e.g. the modified CAD drawing). By concluding the EDC, the engineer effectively moves the EDC from its use state into an archived state, which can be re-used by engineers.

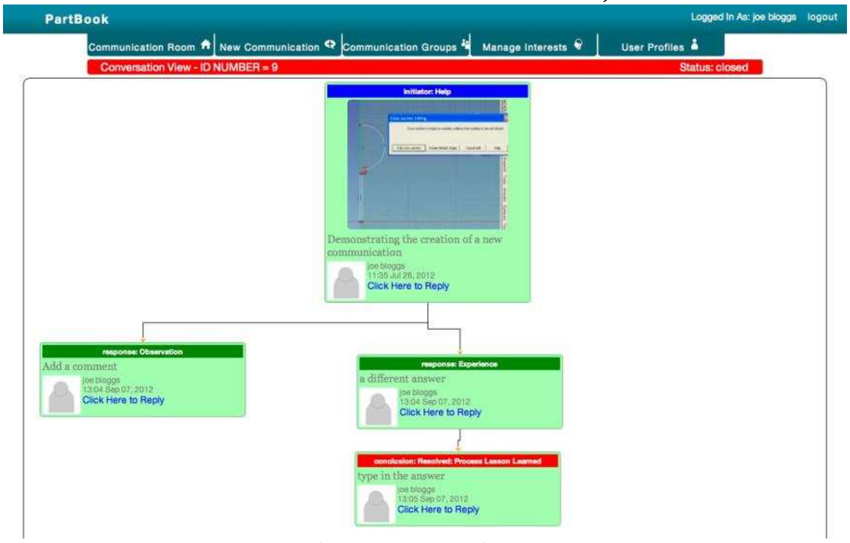

Figure 4: Concluding a Communication

2.4 Hindsight on a Communication

Once the EDC has been concluded, it is made available for re-use. PartBook provides the ability for engineers to comment on past EDCs to show how they have been re-used, to highlight redundancy and best practice, and to make amendments (Figure 5) (R19, R20). As with the response and conclusion elements, engineers are able to direct their comments to the relevant section of the EDC and it is a requirement to provide the reason for the comment to enable analysis and aggregation of EDCs as a whole.

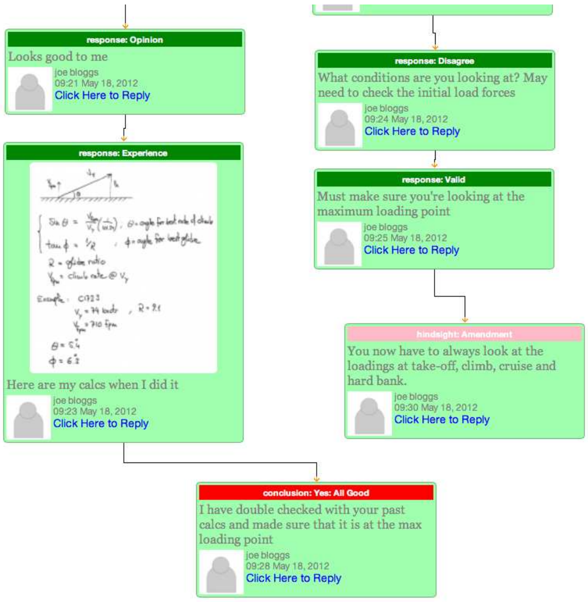

Figure 5: Referring to Past Communications

2.5 Awareness of Communications

PartBook employs a number of features aimed at ensuring the right engineers are made aware of potential EDCs they could participate to. Engineers are able to notify others through the use of tags that can be applied within any textual element (commonly referred to as #tags). For example, @(Joe Bloggs) provides the functionality to notify that use of an EDCs existence (R7) thereby enabling engineers to use their own social knowledge to ensure the right engineers are made aware (R7). In addition, these tags are used within PartBook to group EDCs by personal bookmarks, task and expert groups (R8, R9, R10) and thus enabling awareness to a specific group of engineers be made. #tags are also employed to enable referral between EDCs (i.e. #EDC-234) and thus allow traceability and sharing of rationale within the tool (R18). Finally, engineers are able to take advantage of the tags being stored by each EDC to generate *'Interests'*, which enables a feed of EDCs to be made based upon the engineers preferences (Figure 6).

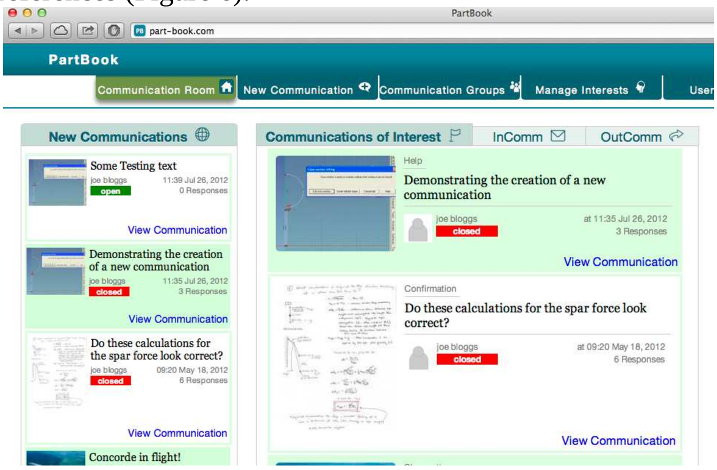

Figure 6: Making Engineers Aware of EDCs

2.6 Summary of PartBooks Solution Specification against the Requirements

To summarise, PartBook is a Social Media tool that meets the requirements to support Engineering Design Communication by instantiating the Social Media Framework developed by Gopsill et al. (2013, In Review). Table 4 provides an overview of the functionality present within PartBook that enables it to meet the requirements.

No.	Requirement to...	Functionality in PartBook
R1	capture the one artefact relating to the purpose of the communication.	Upload of an High–Quality Image
R2	capture high–quality representations of the artefact.	Full–Quality Image upload that can be accessed plus thumbnail for communication views.
R3	enable contributing engineers to support their view by presenting supplementary artefacts limited to one per response.	Image upload and Provision for a URL/Physical Location link.
R4	capture the type of artefact within the representation.	A meta–tag required during the generation of the communication.
R5	capture the focus upon an artefact.	A meta–tag required during the generation of the communication.
R6	provide a link to the actual artefact where possible.	Provision for a URL/Physical Location link.
R7	allow engineers to push communications to one another.	#tag feature to enable engineers to send a notification to a particular engineer at any time of the communication.
R8	enable engineers to group communication by tasks.	#tag feature to enable engineers to group communications by tasks at any time.
R9	enable engineers to push communication to experts based upon domain knowledge required	#tag feature to enable engineers to group communications by experts at any time.
R10	enable engineers to place personal bookmarking upon communications.	#tag feature to enable engineers to group communications by their own personal storage methods at any time.
R11	capture the purpose of the EDC.	A meta–tag required during the generation of the communication. List of purposes outlined in the Communication Classification Matrix
R12	capture the response types of the engineers contributing to the communications.	A meta–tag required during the generation of a response during a communication.
R13	permit the appropriate types of response to the communications.	List of appropriate response types available is determined by the purpose of communication as per the Communication Classification Matrix
R14	ensure an appropriate limit is placed upon the size of the responses.	250 character limit.
R15	enable multiple–threads within a communication.	Multi–threaded communications are enabled through the linking of response elements within the communication.
R16	enable engineers to respond to one or more statement within the communication, thereby enabling divergence/convergence.	Engineers select the elements of the communication they are responding to.
R17	capture the type of conclusion for the communication.	A meta–tag required during the generation of a response during a communication.
R18	enable engineers to refer back to previous communication when making statements.	#tag feature to enable engineers links between communications can be made at any time.
R19	enable engineers to comment on past communications.	Hindsight enable comments to be added after a communication has been concluded.
R20	capture the reason for commenting on past communications.	A meta–tag required during the generation of the comment on the communication. A List of Hindsight types are outlined in the Communication Classification Matrix
R21	capture the company, product and product lifecycle dimensions of the EDC at creation (where applicable).	Meta–tags for the project, activity, product, part, concept, feature & lifecycle are available and can be added during the generation of the communication.

Table 4: Comparison between the Requirements and PartBooks Functionality

3 EVALUATING PARTBOOK THROUGH INDUSTRIAL SCENARIOS

The authors are currently pursuing the evaluation of the tool through three studies that depict fundamental scenarios of the modern Engineering Design Environment, each aimed at a specific needs of the evolving Engineering Design Environment as previously stated in the introduction. The evaluation is looking at determining *'how well'* the tool meets the requirements, its potential in providing further understanding of EDC and *'how well'* it supports communication in a given scenario. This is to be performed through both qualitative and quantitative data analysis.

Qualitative analysis will be through questionnaires and feedback sessions that will provide the participating engineers' perspective. Challenges will lie in ensuring that a shared understanding of the study and the context is provided to the engineers so that they can provide an effective assessment of the tool. Coding of this feedback will aim to assess whether there is a need for amendments to the requirements for supporting Engineering Design Communication or rather it is a usability issue presented by PartBook.

The quantitative data analysis the captured communications within the tool alongside the communications captured using current communication means (for example, E-Mail) will be conducted. In the case of Face-to-Face, it will be requested that participants make notes within a logbook of communication they have had. There will be significant challenges in comparing like communications across the different communication methods used, as well as the tracing of continued discussions from one method to another. Latent Semantic Analysis, Natural Language Processing, Static/Dynamic Network Analysis and Identification of Causal Relationships are currently being proposed to assess whether the additional capture of the EDCs context and relationships to the engineers and product artefact can yield a greater understanding of the evolution of the projects being studied.
Each scenario and description as to the particular aspect of EDC that is of focus is now described.

3.1 Scenario 1: Supporting Knowledge Sharing between Engineers in Variant Product Design

The first study is focused upon the potential for PartBook to enable knowledge sharing within and between two groups of engineers working on variant product design. PartBook will be implemented in the Formula Student project at the University of Bath. Formula Student (FS) is a Motorsport educational programme aimed at developing the next generation of race engineers. Competitions are held worldwide in the UK, US and Europe. Teams of students from their respective universities placed in charge of designing, developing and manufacturing a single-seat race car to compete within the various challenges set-out by the competition. This is also a highly multi-disciplinary and collaborative environment involving the expertise of students undertaking various engineering courses such as automotive, aerospace, electrical and manufacturing.
At the University of Bath, a group of third year students are selected to partake in the FS Competition, who are then tasked with the design and development of the car within their third year, which they continue to manufacture, test and race in their fourth year of study. During the transition from the third to fourth year, the FS competition holds an assessment day where the entrants are required to present their proposed race cars to a board of experts within the Motorsport field. This assessment day has a strong emphasis on the team being able to reason their decisions and demonstrate the rationale behind their designs. In addition, it is a tradition within the University that the third year team develops and produces their own race car, using parts from the previous car only if necessary (for example, springs & dampers). However, there is potential useful knowledge and insights that the fourth year team could share with the new third year team. This situation can be likened to an expert team and a novice team within the context of designing a FS car. It is also the case that currently, there is limited contact between the two teams, as the timescales require considerable time and effort from each member within their own projects activities. Therefore, PartBook’s principal aim within this context is to support the EDCs within the new team, as well as enabling access to the expert team to impart their knowledge on the EDCs and traceability of Design Rationale to aid their performance at the competition.

3.2 Scenario 2: Supporting Knowledge Sharing between Engineers across Concurrent Projects

The second study contrives a multi-project scenario in collaboration with an engineering company looking at improving the comfort of motorbike riders. Postgraduate engineers are to be used to form four teams, where two teams will form the control group and the other, the test group. In each group, one will be tasked to develop a cooling device that attaches to the helmet of a rider and the other will look at attaching a cooling device to the sleeve of the rider. In addition, the teams are only able to contact each other through distributed communication tools and the groups are not permitted to make any contact with one another. This study is simulating multiple projects within a distributed organisation where the technical challenges are similar, thus potential useful knowledge and expertise could be shared between the groups. The control group is only permitted the use of existing collaboration tools typically used in industry (for example, e-mail) whilst the test group will be able to use PartBook. The aim of the study is to analyse PartBooks potential for knowledge sharing across projects in comparison to current engineering practices.

3.3 Scenario 3: Reusability of Stored Knowledge

Finally, the third study looks at the potential in the re-usability of the EDCs stored within PartBook thereby providing an insight into how such a system may manage knowledge build-up. To simulate this, an e-mail corpus from a project within an engineering company is to be re-interpreted as if the EDCs had occurred within PartBook. Engineers from the company and university will be set a number of tasks using either the e-mail corpus or its interpretation in PartBook to assess their understanding and ability to retrieve information from the dataset. The aim of this study is to analyse the potential of PartBook to enable re-usability of stored EDCs in comparison to currently employed e-mail technology.

4 CONCLUSION

Engineering Design Communication (EDC) is used extensively by engineers to support them within the knowledge intensive environment to ensure they receive the right information and make well-informed decisions. However, the ever-more globally distributed Engineering Design Environment is necessitating the use of distributed communication tools that currently do not provide the contextualisation of the environment in which the EDC is being held within when compared to the preferred method of Face-to-Face. Yet, it has been noted by many in the field that supporting EDC could further provide support for engineers real-time work and in doing so capture the design rationale, provide further potential for re-use of the stored EDCs and gain greater insights into the product development process.

Therefore, this paper has discussed how a Social Media tool - PartBook - meets the requirements for supporting EDC from Gopsill et al (2013, In Review). This has been achieved through a four-step communication process and functionality that enables awareness of communications to engineers.

The next steps in evaluating these claims through three studies depicting general industrial scenarios that will use a combination of qualitative and quantitative data analysis has been discussed. Each one looking at a specific challenge from the modern Engineering Design Environment; the knowledge sharing between novice and expert engineers, the knowledge sharing across multiple distributed projects and re-usability of the built-up knowledge base. It has been highlighted that there is significant challenge in ensuring participating engineers have a common understanding of the exercise and thus be able to aggregate results from the questionnaires and feedback session. As well as being able to compare like communications across the different communication methods used and tracing of continued discussions from one method to another.

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