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A Social Media Approach to Support Engineering Design Communication

Gopsill, James

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A Social Media Approach to Support Engineering Design Communication

James Anthony Gopsill

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Department of Mechanical Engineering
University of Bath
UK

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About the Author

James Gopsill has spent seven years studying at the University of Bath. First, completing a Masters of Engineering Degree in Aerospace Engineering, receiving a First with Honours. He then continued his studies at a PhD level. During his studies, he has had experience working for Rolls-Royce as well as collaborating with other aerospace engineering companies during his research.

At the time of writing, he is continuing as a researcher at the University of Bristol looking at the analysis of Engineering Records to facilitate the understanding of project progress and potential project issues that could one day aid future Engineering Project Management. His research interests continue to be in the generation and analysis of large engineering datasets.

http://www.linkedin.com/profile/view?id=277827646
https://bristol.academia.edu/JamesGopsill

"George, I'm in trouble here. I need to construct a case that's as watertight as a mermaid's brassiere. I'm not sure your particular brand of mindless optimism is going to contribute much to the proceedings."

Captain Edmund Blackadder
Corporal Punishment, Blackadder Goes Forth

Abstract

Engineers Talk

Be it through conversations, meetings, informal discussion, phone calls or E-Mail, Engineering Design Communication is the main tributary for the sharing of knowledge, thoughts and ideas, and therefore, fundamental to Engineering Work. An engineer spends a significant portion of their day communicating as they '*fill in the gaps*' left by formal documentation and processes. It is thereby, an inherent source of explicit design rationale that relates to (and very often supplements) Engineering Records and their generation. Engineering Design Communication is not only central for Engineering Work and Records but also offers potential - through aggregation - to reveal underlying features, patterns and signatures that could aid current and future Engineering Project Management.

As Engineering Design Communication plays such a pivotal role, it comes as no surprise that there is much extant research. The majority of this is descriptive and has focused on identifying patterns in engineers' communication behaviour as well as analysing the utility of currently employed communication tools/mediums (such as, E-Mail and meetings). However, little prescriptive research - through either a tool or process - has been undertaken. This may be due to the considerable challenges facing research in this field such as the need to maintain a high-level of Engineering Context, ensure the *right* engineers are able to participate and associate the communication with its respective Engineering Records. All of which, has to be achieved within an Engineering Context where teams are becoming larger, more mobile, multi-disciplinary & distributed, and often performing variant or incremental design.

Although, it is argued that Social Media has the potential to militate these challenges through the use of technologies that provide agile development, support for ubiquitous computing and sharing of multimedia. Therefore, this thesis investigates how Social Media can be used to support Engineering Design Communication. This is achieved through the elicitation and synthesis of the requirements for supporting Engineering Design Communication, and consideration of the effective application of the Social Media. This forms the basis from which a Social Media approach to support Engineering Design Communication is created and then instantiated within a tool called PartBook. PartBook has been developed iteratively and involved an industrial study to evaluate and improve functionality.

It has since been used within an eleven week Formula Student project involving thirty-four students from multiple engineering disciplines in a distributed working environment. The analysis of which addresses the validation of the requirements that has led to amendments and generation of new requirements as well as evaluation of the Social Media approach that has led to insights into the potential impact such a tool could bring to Engineering Work, Records and Project Management.

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Firstly, I would like to thank my parents for all the support they have given me throughout my studies. To my family and friends who have always brought laughter and good times along the PhDs' long and winding road. And to Laura, for always keeping me grounded in reality and to never forget the important things in life.

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Additional

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`http://www.youtube.com/user/flashbuilding`

EPSRC
Engineering and Physical Sciences
Research Council

List of Publications

Listed here are the publications that have been produced by the research presented in this thesis. Their respective abstracts can be viewed in Appendix C.

Journal Articles

"A Social Media Framework to Support Engineering Design Communication" *Journal of Advanced Engineering Informatics*, 2013
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

Conference Papers

"Supporting Engineering Design Communication through a Social Media Tool - Insights for Engineering Project Management", *DESIGN 2014*, Cavtat, Croatia, 2014
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

"An Exploratory Study into Automated Real-Time Categorisation of Engineering E-Mails" *IEEE International Conference on Systems, Man and Cybernetics, SMC2013*, Manchester, United Kingdom, 2013
James A. Gopsill, Steve J. Payne & Ben J. Hicks

"Meeting the Requirements for Supporting Engineering Design Communication – PartBook" *International Conference on Engineering Design, ICED'13*, Seoul, South Korea, 2013
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

"The Communication Patterns of Engineers within an SME in 2012" *International Conference on Engineering Design, ICED'13*, Seoul, South Korea, 2013
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

"PartBook – A Social Media Approach for Capturing Informal Product Knowledge" *DESIGN 2012*, Cavtat, Croatia, 2012
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

"Learning from the Lifecycle: The Capabilities and Limitations of Current Product Lifecycle Practice and Systems," *International Conference on Engineering Design, ICED'11*, Copenhagen, Denmark, 2011
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

"Trends in Technology and their Possible Implication on PLM: Looking Towards 2020," *International Conference on Product Lifecycle Management, PLM'11*, Eindhoven, Netherlands, 2011
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

Working Papers

"Supporting Engineering Design Communication using a custom-built Social Media tool - PartBook", (Journal Paper)
James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

Nomenclature

Provided is a set of definitions used throughout the thesis alongside where they first appear.

Engineering Design
: The activities that generate and develop a product from a need, product idea or technology. (Chapter One)

Engineering Design Communication
: The communication between engineers that pertains to the development of the product. (Chapter One)

Engineering Context
: The external factors that may place further challenges on engineers within Engineering Design. (In Chapter One)

Engineering Project Management
: The planning, monitoring and control of all aspects of a project and the motivation of all those involved to achieve the project objectives on time and to cost, quality and performance (BS 6079). (Chapter One)

Engineering Records
: The data, information and knowledgeable information that is captured and stored across the Product Lifecycle. (Chapter One)

Engineering Work
: The actual activities performed by engineers within Engineering Design (Chapter One)

Social Media
: A concept by which Information Communication Technologies services should be designed in order to support the communication between a group of users. (Chapter One)

Validation
: The determination of whether the hypothesis reflects reality. (Chapter Two)

Evaluation
: The generation of new understanding and utility of an prescriptive measure. (Chapter Two)

Impact
: Understanding the potential affordances of a tool/process/method on Engineering Design. (Chapter Two)

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Chapter 1

Introduction

"Communication is an essential part of any design process"

Clarkson and Eckert [2005]

Engineering Design Communication is intrinsic to the "*fundamentally socio-technical*" activities that is the Engineering Work within Engineering Design [Törlind and Larsson, 2002, Perry and Sanderson, 1998, Robertson, 1997, Badke-Schaub and Frankenberger, 1999]. This is supported by Sim and Duffy [2003], whose analysis of these activities show that almost all require a high level of collaboration between engineers. Engineering Design has also been referred to as a "*knowledge intensive process of communication*", which further demonstrates its importance [Darlington, 2002]. Maier et al. [2005] discusses the highly-contextualised nature of engineers' communication processes and how they enable the transmission of considerable amounts of technical information during the design process. Thus, Engineering Design Communication plays a pivotal role within Engineering Design.

Therefore, it comes as no surprise that there is much literature on the subject and this thesis references work as far back as the 1980s. The literature has primarily focused on the identification of patterns in engineers' communication behaviour and the utility of the communication tools/mediums (such as, E-Mail and Meetings) used in Engineering Design. These two areas are elaborated upon in the following two sections.

1.1 Engineers' Communication Behaviour

Tenopir and Kings' [2004] review of patterns in engineers' communication behaviour shows that there is a consensus among researchers that engineers spend a significant proportion of time conversing with one another, be it either through conversations, meetings, informal discussions, phone calls or E-Mails. Their own work has shown that engineers spend 58% of their time communicating and aligns with similar research in the field.

"Numerous studies corroborate the claim that engineers spend a majority of their time communicating [Hailey, 2000]. Estimates usually range from 40 to 60% of their work time [Hertzum and Pejtersen, 2000], but may be as high as 75% [Nagle, 1998]."

Tenopir and King [2004]

Ellis and Haugan [1997] & Wood and DeLoach [2001] reveal that engineers use communication as a means to seek for information. This is partly due to the fact that colleagues are seen as easily accessible and trustworthy sources of information, and as a consequence they are still preferred over computer-generated search results [Zipperer, 1993, Allard et al., 2009]. A high proportion (69% as recorded by Handel and Herbsleb [2002]) of communication can be colloquially referred to as '*water-cooler conversations*', as it is often a quick informal exchange of knowledge and information between engineers [Larsson et al., 2002, Herbsleb and Mockus, 2003, Poile et al., 2009]. Brown and Duguid [2000] highlight that this communication is heavily relied upon to '*fill in the gaps*' left by formal documentation and process manuals as they can never fully account for every eventuality. This is further supported by Clarkson and Eckert [2005, p.20] showing that engineers use these informal channels in order to be kept informed as well as being able to maintain awareness of project progress. In addition, this informal communication has been found to be the primary means by which professional engineers collect and transfer important information and share ideas [Katz, 1982].

The instances of communication has been shown to be indicative of progress being made and successful Product Development [Liebowitz and Wright, 1999, Griffin and Hauser, 1992, Dougherty, 1987]. Figure 1.1 shows the stark contrast in the instances of communication between successful and failed Product Development and that the instances of communication are much greater in successful Product Development. This is further supported by the Engineering Project Management literature showing that companies see communication as a critical success factor, which affects both productivity and lead-time [Maier et al., 2006, Leenders et al., 2003, Brown and Eisenhardt, 1995]. Dong's [2005] study shows that almost all successful product design teams have high-levels of communication as it aids in the creation of a common understanding[1] between the engineers. High-levels of communication has also been shown to play a key role in reducing '*needless*' uncertainty [Adler, 1995, Daft and Lengel, 1986]. This refers to the difficulties engineers have in receiving the information they require. Be it because they do not discuss it with the *right* engineers or do not know of its existence. '*Needless*' uncertainty is seen as a major factor in causing problems further down the products lifecycle as well as operational inefficiencies [Wood and Agogino, 1996, Jun et al., 2007]. The '*effectiveness*' of communication is often judged by how the tool/medium of interest supports engineers in overcoming the above difficulties. McKelvey and Page [1990] highlights that effective communication enables engineers to draw well-informed conclusions and Yassine et al. [2008] concurs by suggesting that it leads to better engineering decisions being made.

[1]Also known as shared understanding.

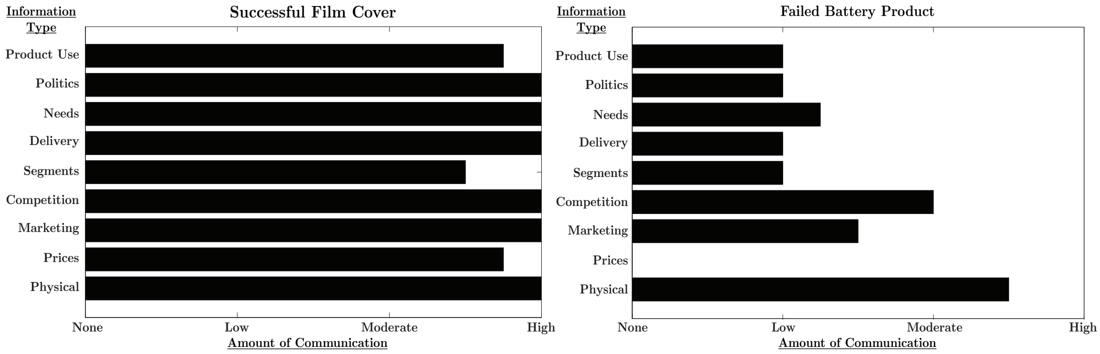


Figure 1.1: Communication - Indicative of Successful Product Development (*From:* Griffin and Hauser [1992], *Re-Illustrated*)

From an individual engineers' perspective, Chiu [2002] discusses how they often have to struggle through a hierarchy of personnel before being able to reach the right people to share knowledge with. In some cases, engineers may simply not know who they should be communicating with [Flanagan et al., 2007]. Olson et al. [2002] has observed that engineers working within the same room are twice as productive as distributed teams and this is due to the ability to converse Face-to-Face more easily. To see this effect, the distributed nature of the team can be as simple as being in two different offices within the same building. The final key feature of engineers' communication behaviour is that of *'gatekeepers'* [Tenopir and King, 2004, Katz, 1982, Tushman and Katz, 1980]. These are key engineers who are known as the '*go to people*' and they are either highly knowledgeable experts who either know or know the location of the expert/piece of information the engineer is seeking. Figure 1.2 demonstrates this fact through the visualisation of E-Mail sent/received between engineers in a four year engineering project.

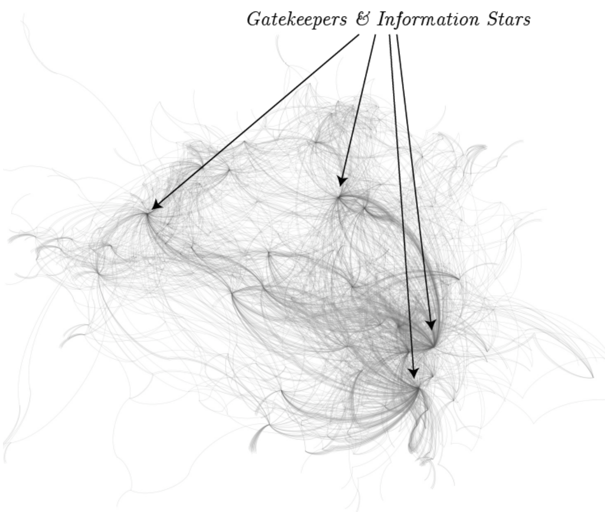


Figure 1.2: Visualisation of an Engineering E-Mail Network

1.2 Utility of Tools/Mediums for Communication within Engineering Design

Moving to the research regarding the utility of the communication tools/mediums used by engineers, it is well documented that engineers prefer Face-to-Face communication above all other means. This is because they are able to convey the necessary context and share/refer to Engineering Records with relative ease [Delinchant et al., 2002, Perry and Sanderson, 1998, Court et al., 1997]. Sim and Duffy [2003] discuss the affordances that mannerisms and expressions bring to Face-to-Face communications in enabling engineers to infer the appropriate context without need to '*think*' about expressing it. This enables informal Face-to-Face communications to be quick with Whittaker et al. [1994] showing that they typically last an average of 1.9 minutes compared to more formal discussions held in meeting rooms that take 13.1 minutes on average.

Meetings are often seen as a formal means of communicating information and are used extensively within engineering. Olson et al. [1992] analysis of ten design meetings reveals that they contain many communication instances with 40% of them discussing the design, 30% providing summaries of progress made and the remaining 30% spent on coordinating and clarifying points made. Further, it is often seen as the main means by which a mass of information (such as reports, models and results) is aggregated and discussed. These discussions often result in a number of decisions being made as to the direction of the design [Conway et al., 2007].

As teams become distributed, E-Mail takes over as the dominant communication tool [Herbsleb and Mockus, 2003]. Although, this has only been a recent change within the past decade with Telephone previously being the main distributed communication method [Vest et al., 1996, Sosa et al., 2002, Gopsill et al., 2013a]. The prominence of E-Mail is argued to be due to companies' offering support for the communication method and its ubiquity across the entire industry [Delinchant et al., 2002]. This is in addition to offering asynchronous communication and reducing the burden of social interaction on engineers [Tenopir and King, 2004, Eckert et al., 2001].

Although, Morelli et al. [1995] & Eckert et al. [2001] reveal that the instances of distributed communication remains much lower when compared to the instances of Face-to-Face communication and it is argued that the tools used for distributed communication are creating a barrier in preventing similar volumes being observed. Chiu [2002] highlights that the current tools employed by engineering companies to support communication do not provide the interaction required for Engineering Design Communication. This is supported by Popolov et al. [2000] who discuss how E-Mail struggles to cope with collaborative communications as only few engineers are typically involved and the engineers needs prior knowledge of who to send it to. This prerequisite to direct the communication to specific engineers can limit contributions from the *right* engineers due to lack of awareness [Schneider et al., 2008]. This is compounded further by the fact that current tools make it difficult for others to view and share communications amongst the community of engineers within the company. Allen [2000] refers to this as a lack of '*richness*' provided by the current tools, which also includes the inability for the tool to associate the appropriate Engineering Context with the communication. This can lead to communication breakdown as a '*common*' understanding cannot be achieved. Orlikowski et al. [1995] & Eppler and Mengis [2004] also question the suitability of E-Mail to support Engineering Design Communication due to the constant need for intervention and guidance on the appropriate use and governance. Finally, in almost all instances, limits are imposed on E-Mail. The restriction of an E-Mails size is one such example and can lead to issues in the sharing of Engineering Records. Also, restricting the size of engineers' personal E-Mail storage can lead to potentially re-usable communications being lost through deletion [Orlikowski et al., 1995, Dabbish and Kraut, 2006, Gantz and Reinsel, 2007].

This is an area of potential concern because the Engineering Context is seeing a continued trend towards engineering teams that are becoming larger as well as more mobile, multidisciplinary and distributed. Thereby, necessitating the use of more distributed communication tools. In addition to the evolving Engineering Context, much of the research in this field has been of a descriptive nature. Tenopir and King [2004] discuss how current research often relies on surveys and/or interviews as a means of data capture and that there are potential limitations on the understanding that can be generated from them. Clarkson and Eckert [2005] go further to suggest that the field is reaching a plateau of understanding and intervention research is required to further the field. The few pieces of prescriptive research that have been undertaken have studied the introduction of new computer-mediated communication tools and how Engineering Design Communication is affected [Törlind and Larsson, 2002, Höllta, 2011]. These have employed off-the-shelf tools rather than a custom-built tool dedicated to supporting Engineering Design Communication. Thus, there is a substantial gap within the field to provide prescriptive measures to support Engineering Design Communication, be it through the development of a tool or process that is based on what is required in order to support Engineering Design Communication. Although, there are a number of associated challenges that need to be overcome so that this can be achieved.

1.3 Challenges in Supporting Engineering Design Communication

Tenopir and King [2004] & Maiden and Bright [1996] discuss the need for a tool to be able to provide a similar level of context to Face-to-Face communication and the ability for collaboration in order to solve problems, discuss issues and/or make decisions effectively. Pahl et al. [2007] & Tushman and Katz [1980] also show that interdisciplinary teams adapt and use terminology that meets their needs, however, this poses a challenge if other engineers participate in the communication.

There is also a challenge in facilitating communications between the right knowledgeable engineers. Ensuring engineers are made aware of communications in which they may be able to participate is a must for any distributed communication tool [Clarkson and Eckert, 2005, Maier et al., 2006, 2008, Flanagan et al., 2007]. Leckie et al. [1996] & Lowe et al. [2004b] show that there is a huge variety in how engineers seek and share information, which is often accompanied by Engineering Records [Eckert and Boujut, 2003, Carlile, 2002, Hicks et al., 2008]. In addition, it has been shown that engineers seek information from a variety of perspectives (such as where it originates from within the company, product and project). Thus, there is a need to consider these dimensions when supporting Engineering Design Communication to enable effective search & retrieval [Ahmed and Wallace, 2004]. Sim and Duffy [2003] discuss how communication has a strong interplay between the engineers and the evolution of Engineering Records. Therefore, it is argued that any communication tool needs to consider how to represent/capture all the above relationships. Finally, Al-Rawas and Easterbrook [1996] sum up the challenges as:

1. *The Ineffectiveness of the Current Communication Tools* to support distributed Engineering Design Communication due to inability to capture the engineering context.
2. *The Restrictions on Expression within Communication Tools* and particularly in enabling engineers to collaborate in a more natural way.
3. *The Social and Organisational Challenges,* which include ensuring there is awareness of the communication to enable the right engineers to contribute and ensure the right dimensions are captured alongside the communication to enable easy search and retrieval.

As the current communication tools and thereby technologies used within engineering are not providing the required support for Engineering Design Communication, it is proposed that Social Media may be a suitable alternative. The reasoning behind this proposition is now discussed.

1.4 Social Media - The Technologies to Overcome the Challenges

Social Media (SM) has developed significantly over the past decade and the tools are becoming increasingly central to the digital lives of individuals [Madden and Zickuhr, 2011, Kaplan and Haenlein, 2010]. They are often underpinned by web/mobile-based technologies and their design is focused on supporting communication within a computer-mediated environment [Ellison et al., 2007]. Although, SM is not simply an application but rather, the concept of using technologies to better support the communication within a given community. Annanperä and Markkula [2010] simply defines them as:

> "technical solutions that have been designed to help people to communicate"
>
> Annanperä and Markkula [2010]

Thus, this highlights that SM concerns the development of an approach with respect to how one would support the communication of interest [Weinberg and Pehlivan, 2011, Safko, 2010]. In addition, Boyd and Ellison [2007] highlights three key elements that a tool is required to meet in order to be considered a Social Media tool. They need to allow the users to:

1. construct a public or semi-public profile within a bounded system.
2. articulate a list of others with whom they share a connection.
3. view and traverse their list of connections and those made by others within the systems.

Considering Social Media with respect to Engineering Design Communication, Törlind and Larsson [2002] expresses the need for any tool that supports Engineering Design Communication to be lightweight and SM has been described as such [Zhao and Rosson, 2009, Whittaker et al., 1997, Brzozowski, 2009]. Further, SM tools generally support synchronous and asynchronous communication, which has benefits in enabling communications to continue independent of users' schedules, time differences and location [Poile et al., 2009]. In addition, as new generations of engineers are increasingly using SM tools as their main means of social communication, it can be seen as pertinent to consider the support of such technologies within Engineering

Design. Some industries are already beginning to use SM tools to support their communication and therefore, it is argued that there is a sense of inevitability that such tools will be used, as was the case for E-Mail over a decade ago [Black et al., 2010].

Alavi and Leidners' [2001] review of communication tools to support knowledge sharing considers electronic bulletin boards and discussion forums as the most suitable technologies. It is argued that these can be considered precursor technologies to SM with the main difference being that they maintain a hierarchical storage structure for communications. As SM does not provide this structure for its content, the content can be associated with multiple-facets without issue. In order to achieve this, SM tools generally employ user and collaborative tagging functionality to increase the level of context surrounding an information object or communication within the system. This is in addition to storing core meta data such as author, date of creation and location [Ames and Naaman, 2007, Golder and Huberman, 2006]. For example, the popular FaceBook uses tags within photos to identify people and link the photo to that user (Figure 1.3). Functionality such as tagging could provide the ability to capture the relevant Engineering Context to support Engineering Design Communication. Finally, an interview with Mark Zuckerberg[2] suggests Social Media tools are 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 knowledgeable engineers.

Figure 1.3: An example of tagging content within a Social Media tool (*From:* business2community)

Although the development of a SM tool may seem a suitable approach to take for supporting Engineering Design Communication, there is a need to consider and ensure that the technologies underpinning the tool are applied appropriately. If achieved, there are a number of potential benefits to providing an approach to support Engineering Design Communication.

1.5 Engineering Records and Project Management

Supporting Engineering Design Communication would not only overcome the challenges previously stated and in doing so look to aid Engineering Work, but there are also a number of potential affordances with respect to Engineering Records and Project Management.

In terms of Engineering Records, Engineering Design Communication often contains the rationale behind decisions made and insights/conclusions drawn from the discussion and aggregation of information [Huet et al., 2007]. This can be used to describe the evolution of Engineering Records [Regli et al., 2000]. Dearden [2006] supports this by describing the idea

[2] Founder of FaceBook

of 'material utterances', which are changes within records (i.e. modifications/changes to documentation and/or files) and that communication is often the cause. A number of studies have shown that engineers use as much as 70-95% of past designs to develop new, variant or incremental products [Eckert et al., 2001, Freund et al., 2005, Vijaykumar and Chakrabarti, 2008]. Therefore, being able to understand the reasoning behind the evolution of the design could aid the re-use of Engineering Records and also reduce unnecessary Engineering Work through the ability to highlight potential re-occurrences.

It is recognised that the capture of design rationale has - in part - been attempted through the application of argumentative capture tools [Shipman and McCall, 1997, Klein, 1993]. Figure 1.4 shows a screen-shot of one such tool - the Design Rationale editor (DRed) - where engineers can reason the decisions made in meetings. Implementation of these tools has often led to engineers having an increased workload as they are required to post-rationalise the design process once the project/task has finished [Bracewell et al., 2004, 2009, Shum et al., 2002, Zhang et al., 2012]. Carlile [2002] discusses that knowledge gained by engineers is embedded in practice and therefore it is hard to recall and articulate. This raises issues about the utility of current approaches for design rationale capture. In contrast, supporting Engineering Design Communication would capture the real-time embedded rationale within the communication and therefore, would not require an additional workload for the engineers. Thus, some of the results later in this thesis may resemble what one would expect from a Design Rationale tool even though the primary goal is one of supporting Engineering Design Communication.

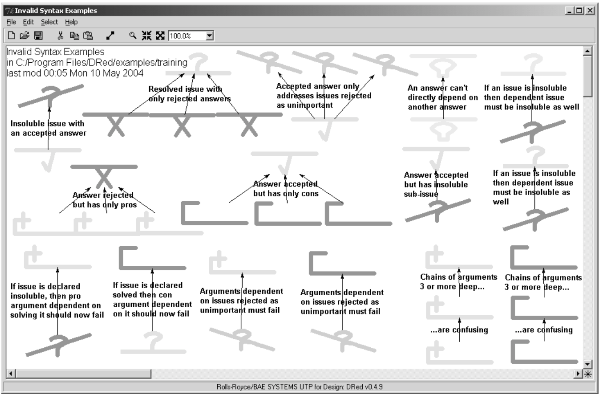


Figure 1.4: An example of the Design Rationale editor (DRed) tool (*From:* Bracewell et al. [2004])

Taking an Engineering Project Management perspective, the aggregation and analysis of content within communications could lead to the identification of events, patterns and signatures. This has been explored to some extent by Wasiak [2010], whose analysis of an engineering e-mail corpus during a project saw the exchange of various categories of e-mail change over the course of the project (Figure 1.5). Further, Gopsill et al. [2013b] reveals that there is potential in eliciting the purpose of an E-Mail based upon its content and that patterns in the volume of these various types of E-Mails could align to specific project events. The identification of events, patterns and signatures could

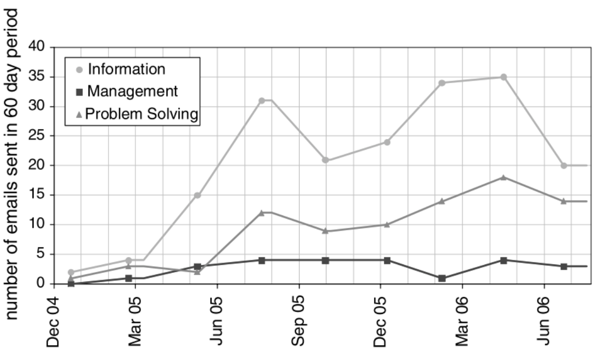


Figure 1.5: Patterns within Engineering Communication (*From:* Wasiak et al. [2009])

provide Engineering Project Management with greater insight into the progress of the project and where intervention may be required. The analysis of the communications content could be used to form knowledge/expertise representations of the engineers involved in the project.

Finally, Clarkson and Eckert [2005, p.20] reveal that although engineers make considerable use of this - often informal - communication, they do resent the fact that it is not official company policy. Therefore, providing support for this communication would enable engineering companies to acknowledge its importance and thus, reduce this resentment and potentially further encourage the sharing of knowledge and communication through Engineering Design Communication.

It is this gap in the research alongside the associated challenges and potential in overcoming them that is addressed in this thesis and gives rise to the research aim:

Aim

To investigate how Social Media can be used to support Engineering Design Communication.

In order to discuss this research, the thesis is structured as follows (Table 1.1):

Chapter 2: Literature Review: Defining the Research Context

The Introduction has focused on Engineering Design Communication. This chapter provides the wider context in which this research is placed. Description and summary of the research related to the terms; Engineering Design, Context, Work, Records and Project Management is made.

Chapter 3: Research Methodology

This chapter discusses the aim of the research and expands it into three Research Questions. A brief review of the past research methods used in this field is presented as well as the research approach of this thesis.

Chapter 4: The Requirements for Supporting Engineering Design Communication

In order to understand how to support Engineering Design Communication, this chapter elicits and synthesises the requirements for the support of this communication from the literature.

Chapter 5: The Effective Application of Social Media

This chapter reviews the literature regarding Social Media from both a conceptual and real application perspective. The output is a set of considerations to ensure that Social Media is applied effectively.

Chapter 6: A Social Media Approach to Support Engineering Design Communication

Through the combination of the requirements for supporting Engineering Design Communication and considerations to ensure the effective application of Social Media, this chapter presents a proposed Social Media approach.

Chapter 7: Development of a Social Media tool - PartBook

This chapter discusses the development of a tool known as PartBook, which instantiates the Social Media approach presented in Chapter 6. The tool developed iteratively alongside the approach as well as being tested by an industrial user group.

Chapter 8: Formula Student Study	
This chapter discusses the context of the study to validate & evaluate the Social Media approach to support Engineering Design Communication. A summary of the generated dataset and implications of usability are also discussed.	
Chapter 9: Validating the Requirements & Social Media Considerations	
This chapter presents the analysis of the Formula Student dataset with the objective of closing the loop on the requirements and considerations generated from Chapters 4 & 5.	
Chapter 10: Evaluating the Social Media Approach	
This chapter presents the analysis of the Formula Student dataset with respect to assessing the impact of the Social Media approach on Engineering Work, Engineering Records & Engineering Project Management.	
Chapter 11: Discussion & Conclusion	
This chapter discusses the work presented in this thesis, looks at avenues for future work and defines the contributions to knowledge it makes.	

Table 1.1: The Structure of the Thesis

1.6 Chapter Summary

The Introduction has shown the importance and fundamental nature of communication in Engineering Design. Past research has been primarily of a descriptive nature and has either focused on the identification of patterns in engineers' communication behaviour or utility of the communication tools/mediums used in Engineering Design. Discussion of this literature has led to the discovery of a research gap in supporting Engineering Design Communication using distributed communication tools. The associated challenges, suitability of a Social Media approach and potential in closing this gap are expressed and results in the aim; to investigate how Social Media can be used to support Engineering Design Communication. This has been followed by a description of the structure of the thesis.

Chapter 2

Literature Review: Defining the Research Context

The Introduction has highlighted and focused on the central role that communication plays within Engineering Design. From this, the identification of the research gap, associated challenges and potential in closing this gap has been made, together with how the use of Social Media may be a suitable avenue to pursue in order to close this gap.

Thus, the description of the previously used terms; Engineering Design, Engineering Context, Engineering Work, Engineering Records and Engineering Project Management have been omitted. Therefore, this chapter addresses this by discussing what is meant by the above terms and how communication is related to each of these areas. From this, a summary of the research context is formed and re-iteration of the research gap is made.

2.1 Engineering Design

Engineering Design is a part of human nature as a mean to improve our daily lives and is a at the intersection of Engineering Science, Economics, Engineering Technology and Industrial Design (Figure 2.1) [Semaw et al., 1997, Pahl et al., 2007] . Modern Engineering Design usually involves a number of individuals working together to generate a product and/or - more recently - a product service [Mont, 2002]. Blessing and Chakrabarti [2009, p.1] considers Engineering Design as the '*activities that actually generate and develop a product from a need, product idea or technology*'. These activities involve the creative application of scientific principles in combination with the engineers' own technical understanding

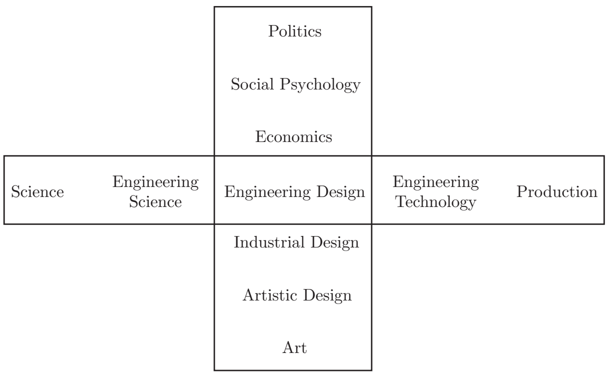


Figure 2.1: The Engineering Design Intersect (*From:* Pahl et al. [2007], *Re-Illustrated*)

and expertise [Pahl et al., 2007, Cross et al., 1996]. In order to manage Engineering Design, a number of design process models, such as systematic, stage-gate, vee and cyclic models, have been developed [Tomiyama et al., 2009, Pahl et al., 2007, Pugh, 1991, French, 1998, Cross, 1989, Ullman, 1997, Cooper, 1990]. Figure 2.2 provides an example of one such model.

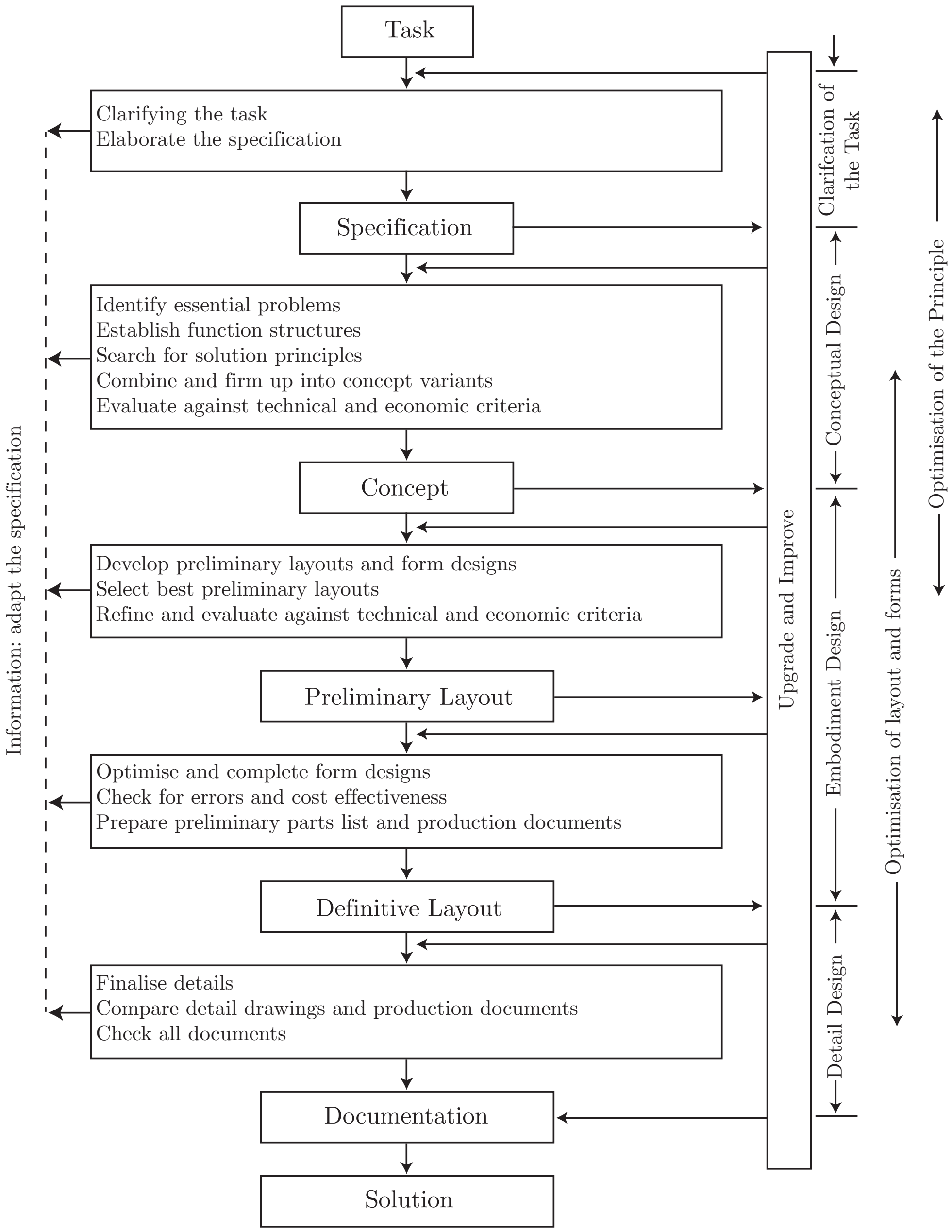


Figure 2.2: Pahl and Beitz Systematic Design Process Model (*From:* Pahl et al. [2007], *Re-Illustrated*)

However, independent of the definitions used for Engineering Design or by which model a particular companies' Engineering Design process follows, it is widely accepted that Engineering Design is "*fundamentally socio-technical*" and that communication is an intrinsic part [Törlind and Larsson, 2002, Perry and Sanderson, 1998, Badke-Schaub and Frankenberger, 1999]. Darlington [2002] goes as far as saying that Engineering Design is a *"knowledge intensive process of communication"*. This is further supported by Maier et al. [2005] who discuss design as a technical and social process where considerable technical information is transmitted through highly-contextualised communication processes, and Sim and Duffy [2003], whose analysis of Engineering Design show that almost all activities have a requirement for a high degree of collaboration between engineers. Therefore, as highlighted by Clarkson and Eckert [2005] and re-iterated in this thesis:

"Communication is an essential part of any design process"

Clarkson and Eckert [2005]

Therefore, it is argued that the understanding and support of communication related to Engineering Design must be a primary focus of Engineering Design Research.

Although, the definition of Engineering Design and the research into the process by which it is conducted has been discussed, it is important to note that Engineering Design Research is far more diverse. This diversity has been discussed at length in the early years of Engineering Design Research by Finger and Dixons' two part review [1989a, 1989b]. It highlighted six fundamental areas: descriptive models, prescriptive models, computer-based models of the design process, languages, representations, analysis in support of design, and design for manufacture & the life cycle. This breadth of research has led to issues for future researchers in being able to draw generalisable conclusions as previous results are heavily dependent on the context of the study [Horváth, 2004]. Little explanation of the research context leads to difficulties in being able to re-use and corroborate across multiple studies. It is now becoming the case that design research is being driven by the need have a practical significance as well as furthering scientific knowledge [Cash, 2012]. '*Impact*' has been the term given to these drivers and its manifestation can come in various forms such as:

- Improving practice (e.g. Bergström and Törlind [2005])
- Innovation [Ulijn and Weggeman, 2001, Howard et al., 2008]
- Improving understanding [Design-Society, 2013, Cross, 2004]
- Improving integration between research and practice [Design-Society, 2013]
- Providing valid metrics [Hicks et al., 2007]
- Providing viable models [Hicks et al., 2007]

From: Cash [2012]

These can all be seen as a means to support Engineering Design and this is supported by Duffy and O'donnell [1998] who state that "*Design research is directed at gaining a greater understanding of design, ultimately in order to better support it through the development of improved techniques, methods or tools*". This can be achieved through the validation of hypotheses and through the evaluation of tools/methods to support Engineering Design. Where Validation and Evaluation are described as:

Validation
The confirmation that the hypotheses are true to reality.

Evaluation
The determination of a subject's merit, worth and/or significance.

Therefore, this thesis uses Blessing and Chakrabarti [2009, p.1] definition of Engineering Design as the '*activities that actually generate and develop a product from a need, product idea or technology*'. Where communication plays a fundamental role throughout these activities independent of the process model being employed. Thus, it is argued that it is a core area for Engineering Design Research to understand and support. In order to do so, the research undertaken should have a clear explanation of its context alongside results that both further scientific knowledge and have a practical significance, and look to both validate and evaluate. This thesis places the importance on providing support for communication related to Engineering Design, hence known as Engineering Design Communication.

2.2 Engineering Context

In order to meet the needs of their customers and to give themselves a competitive advantage, engineering companies are developing products that increasingly require the integration of features from multiple engineering domains. As the complexity of the products increases, so does the investment required at the early stage of design. In some industries - particularly High Value, Low Volume - the investment has reached a point where the traditional business models of selling a product have become infeasible [Rink and Swan, 1979]. Therefore, engineering companies are moving towards the delivery of Product Service Systems to better manage their assets and finances [Johnstone et al., 2009, Baines et al., 2007]. Mont [2002] describes this as the 'sale of use' of the product as opposed to the sale of the product. An additional driver for this business strategy is from the increasing responsibility that the originating company has on the appropriate disposal of their products [Pnueli and Zussman, 1997, Toffel, 2003]. Retaining asset ownership enables engineering companies to better manage the environmental impact. Thus, engineers are having to consider - to an even greater extent - the impact of the product over its entire life cycle. This is paramount as it is accepted that approximately 70% of the committed cost is associated with the design phase (Figure 2.3) [Asiedu and Gu, 1998, Wang et al., 2002]. Therefore, communication with colleagues across the product lifecycle is becoming more important to ensure knowledge is shared to address the above challenges.

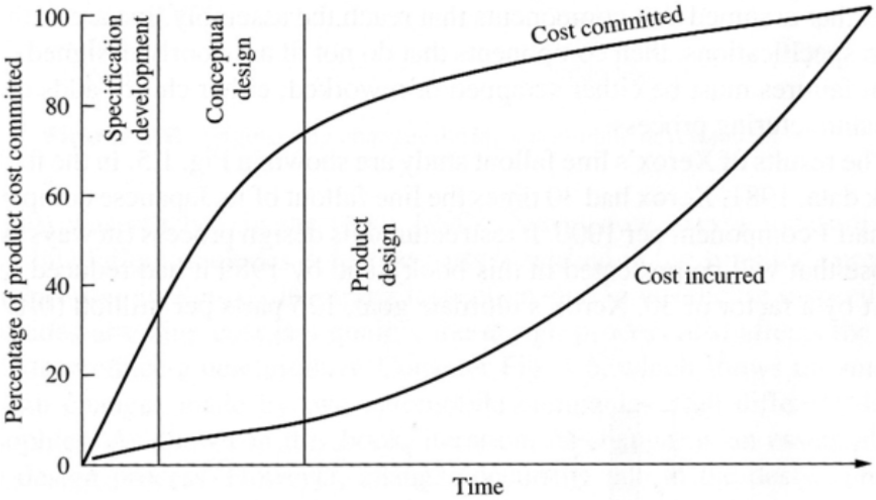


Figure 2.3: Cost of an Engineering Project (*From:* Ullman [1997])

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

Table 2.1: Product Build-Up (*Source*: Wikipedia)

In addition, many engineering companies have an increasing build-up of past products (Table 2.1). In generating these products, a considerable number of Engineering Records are produced. With a life expectancy of these records reaching the decades, there is an ever-increasing volume of available knowledge and information that can be potentially re-used and built upon by engineers [Harris, 1996]. To provide some values, McMahon et al. [2004] study on the search & retrieval of Engineering Records analysed a portion of a shared network drive that contained 38,500 files, Wasiaks' [2010] work on analysing the content of engineering E-Mail covered some 10,000 E-Mails from a single project and the dataset generated by this thesis contains approximately 1,000 captured communications and 13,500 digital files.

In many cases, engineers use in the region of 70-95% of the previous design in new product development [Vijaykumar and Chakrabarti, 2008]. This has been due to the need to consider the product across its entire lifecycle as they can iterate and improve from the last version. Also, it is due to the need to reduce the time-to-market so that the company can remain competitive. This is no more evident than in the current mobile phone industry (Figure 2.4). However, the worry is that of information overload, whereby engineers are overwhelmed by the sheer volume of information and thus, unable to identify the most pertinent records for their task [Edmunds and Morris, 2000, Eppler and Mengis, 2004]. Stock et al. [2001] describes how engineers have an inverted u-shape in their absorptive capacity suggesting too little or too much may hinder their performance. Vajna [2005, p.367] discusses how usually '*it is hard (if not impossible) to find the right documents, data or information at the right time. Therefore, it is difficult to finish the work quickly and to appropriate levels of quality*'.

It remains the case that engineers communicate with colleagues in order to overcome the above challenges in retrieving records as they are seen as easy accessible and trustworthy sources of information [Zipperer, 1993]. Even with the advent of search engines [Allard et al., 2009]. One of the key benefits of communities of practice is that there is a shared understanding of the information stored within the Information Systems employed and that colleagues can easily communicate the location of the most pertinent information [Correia et al., 2009, Sharratt and Usoro, 2003, Lesser and Storck, 2001]. Therefore, it is argued that by supporting Engineering Design Communication, it could further aid in the search, retrieval and re-use of the ever-expanding volume of Engineering Records.

images/removed-1.jpg

Figure 2.4: Evolution of the iPhone - Infographic (*From:* en.rain.ru)

images/removed-2.png

Figure 2.5: Airbus Distributed Design and Manufacture (*From:* Airbus)

To remain competitive and reduce costs further, the environment in which engineers design and manufacture products is becoming ever more geographically distributed. Airbus is one such example (Figure 2.5). This is leading to teams having to deal with different time-zones, cultures and engineering terminology [Hietikko and Rajaniemi, 2010, Tushman and Katz, 1980]. Communication and sharing of information between distributed teams is crucial in preventing conflict [Hinds and Bailey, 2003]. Although, much conflict still remains as the current information communication technologies employed do not aid in developing a shared understanding of the project across the teams. It is also the case that as teams become distributed, engineers are becoming more mobile as they are either having meetings with distributed team members or going to and from different offices/sites where they '*hot*' desk [Bellotti and Bly, 1996]. This increased mobility leads to the preferred method of Face-to-Face communication becoming more difficult - as the engineer is not there - and leads to increased use of distributed communication methods/tools that perform independent of temporal and spatial constraints.

Therefore, the Engineering Context considers the external factors that are placing further challenges on engineers within Engineering Design. These have been highlighted as the need to consider - to an even greater extent - the impact of the product across its entire life cycle, and the need to support the search, retrieval and re-use of past records in an ever-expanding information set. Communication plays a pivotal role in overcoming these challenges. However, the trend towards ever-more distributed teams is leading to the greater use of distributed communication tools (i.e. E-Mail) and currently, these tools do not provide the support required for Engineering Design Communication as previously discussed in 1.2. Hence, the research gap that this thesis seeks to fill.

2.3 Engineering Work

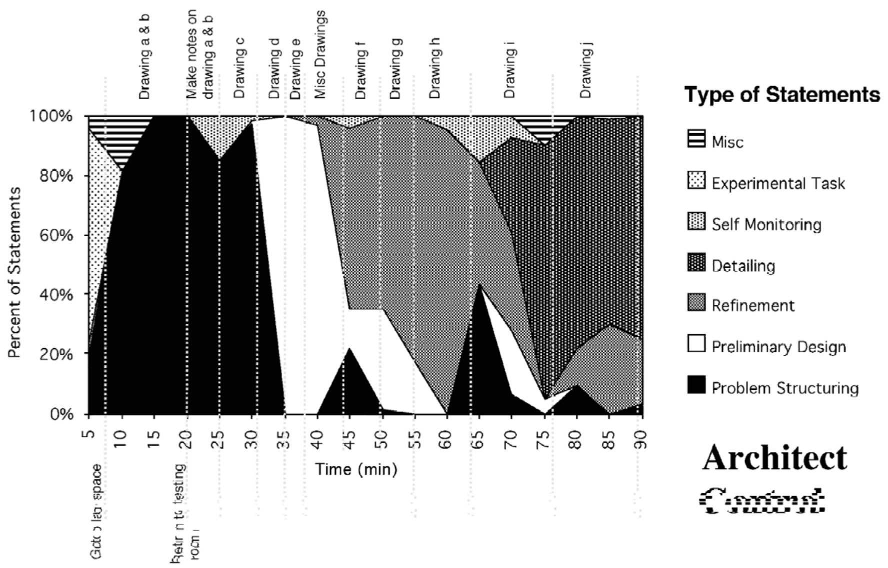
Engineering Work considers the actual activities performed by engineers in their day-today work. Engineering activities require engineers to have the ability to solve problems, issues and queries, make decisions and share knowledge [Krishnan and Ulrich, 2001, Brown and Eisenhardt, 1995]. Table 2.2 presents Sim and Duffy's [2004] aggregation of engineering activities and highlights three core activity types.

Design Definition Activities
Abstracting, Associating, Decomposing, Defining, Generating, Standardising, Structuring/Configuring & Synthesising
Design Evaluation Activities
Modelling, Analysing, Testing/Experimenting, Evaluating, Decision Making, Determining & Verifying
Design Management Activities
Constraining, Exploring, Identifying, Information Gathering, Planning, Prioritising, Resolving, Scheduling, Selecting & Searching

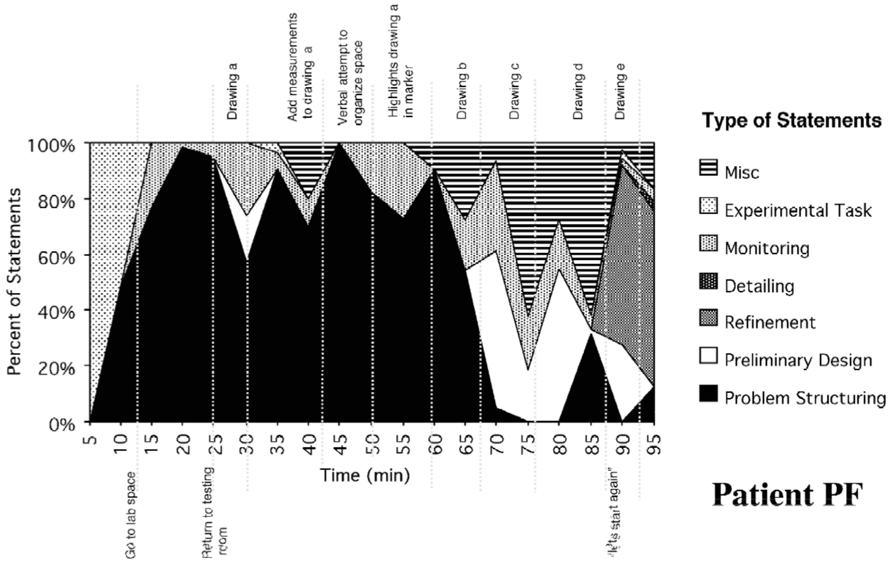
Table 2.2: Design Activities (*From*: Sim and Duffy [2004])

They are often highly collaborative and require considerable communication, and use of shared resources between the engineers involved [Bellotti and Bly, 1996]. Ostergaard and Summers [2009] have studied the variables that define the collaborative nature of these activities for the purpose of aligning the many studies in the area. This enables generalisable results to be attained.

Aggregating across the literature, it may come as a surprise that approximately a third of an engineers time is spent performing the design activity. This is where research has looked into assessing the attributes of the engineer performing the task, such as creativity, knowledge and expertise [Snider et al., 2013, Cross and Cross, 1998]. Goel and Grafman's [2000] neurological study revealed how an engineers cognition affected the ability of the engineers to perform a design task (Figure 2.6). The study used 'think-aloud' protocol analysis in order to understand what the engineers were attempting to do during the task. It is argued that the rationale contained within Engineering Design Communications could be likened to the 'think-aloud' protocol analysis and may contain information that could identify these attributes over the course of an Engineering Project. It is then hypothesised that engineering teams could be better organised and managed from the analysis of this information.



(a) Architect



(b) Architect with a lesion on the right prefrontal cortex

Figure 2.6: The effect of a lesion on the right pre-frontal cortex on the design thinking of an architect (*From:* Goel and Grafman [2000])

Another 20-30% of their time spent is seeking for Engineering Records[1] or other engineers [Tenopir and King, 2004, Freund et al., 2005, Court et al., 1998, Lowe et al., 2004a]. Hertzum and Pejtersen [2000] discuss how the seeking of Engineering Records and other engineers are intertwined. Highlighting how records are often used to identify an engineer with whom to speak and how communication with other engineers is used to retrieve records. This is because the records are often a statement of fact whilst the engineers can discuss the rationale behind these facts. They are both required by an engineer in their activities. Activities at the initial phase of the project are likely to have a large component of record seeking [Ellis and Haugan, 1997]. This reduces as the design progresses and is further defined/constrained, where more directed and focused seeking occurs.

The majority of the time is spent on engineers communicating. Tenopir and King [2004, p. 30] show it as around 58% and their review states that:

> "Numerous studies corroborate the claim that engineers spend a majority of their time communicating [Hailey, 2000]. Estimates usually range from 40 to 60% of their work time [Hertzum and Pejtersen, 2000], but may be as high as 75% [Nagle, 1998]."

Tenopir and King [2004]

Handel and Herbsleb [2002] indicate that a high proportion of this communication can be colloquially referred to as '*water-cooler conversation*' due to the fact that they are often a quick informal exchange of knowledge and information between engineers [Larsson et al., 2002, Herbsleb and Mockus, 2003, Poile et al., 2009]. Kraut and Streeter [1995] refers to them as the opportunistic and/or spontaneous communication, and that they are more abundant than scheduled and/or intended communications.

Its sizeable contribution to an engineers typical day is not without purpose. Communication is often use to '*fill in the gaps*' left behind formal engineering records and therefore enables the engineer to continue on with his work [Brown and Duguid, 2000]. It is also used by engineers in order to be kept informed of project occurrences, thereby enabling them to maintain an awareness of the overall project progress [Clarkson and Eckert, 2005, p.20]. Katz [1982] highlights that communication is the main form by which the main outcomes of an activity are expressed and is supported by a more in-depth account in the form of an Engineering Record.

In light of this discussion, Engineering Work pertains to the actual activities performed by engineers within Engineering Design. To which, communication features heavily and has a crucial role to play in the form of enabling engineers to share information & knowledge, maintain awareness of project progress and deliver the key outcomes of their activities. Supporting Engineering Design Communication would need to ensure that this can continue.

2.4 Engineering Records

At a conceptual level, this thesis takes the knowledge vis-à-vis data and information perspective from Alavi and Leidners' [2001] review, which views data and information hierarchically. Therefore, Engineering Records are to be considered as one of three types; data, information

[1] Often referred to as Information Seeking

or knowledgeable information. Data records contain raw numbers, facts and values that lack any context such as a generic file of values. It is often the case that there is some level of context associated with the data and this is referred to as information. For example, the previous generic file of values was an engine temperature sensor file. Records are knowledgeable information when an engineer provides an interpretation such as a report on why deviation is appearing on engine temperature (for example). The fundamental difference between the two types of information is that the latter cannot be automatically generated. Therefore, a record of communication is considered to be knowledgeable information. Table 2.3 summarises these three conceptual types of Engineering Record.

Record Type	Description
Data	Raw numbers, facts and values without context thereby providing the engineer with no discernible meaning.
Information	Data that contains some level of context enabling the engineer to generate meaning.
Knowledgeable Information	Information that contains human interpretation that cannot be automatically generated.

Table 2.3: Three Conceptual Types of Engineering Record

In the practical sense, the output of Engineering Work generally includes one or more types of documentation/objects such as reports, prototypes, notes, results files, Computer Aided Design (CAD) files and engineering drawings to name a few [Sim and Duffy, 2003]. These are the Engineering Records that are used to describe and develop the product throughout the design process. What each type of record can describe about the product can vary significantly even if the file type is the same [Hicks et al., 2006]. For example, a word document can contain notes, meeting minutes, instructions or a formal report. In order to manage the variety in content, purpose, the dependencies upon one another and their evolution during Product Development, a considerable number of information systems have been implemented within engineering companies. Figure 2.7 shows eleven common types of Enterprise Wide System along with twenty nine high-level types of documentation that have been highlighted by Gopsill et al. [2011] review. It is argued that this review was not exhaustive and therefore there is potentially many more systems in use within engineering companies.

The application of information systems has become an integral part to supporting Engineering Work as a means to overcome the traditional traceability and process bottlenecks inherent in paper-based documentation [Ives and Learmonth, 1984, Roy et al., 2004]. A case study by Argyres [1999] further highlights this by confirming that the development of 'very-high' technological aircraft would not be feasible. If properly implemented, information systems can increase the productivity of development teams [Dyer and Nobeoka, 2000]. Although, the number of systems does pose challenges, which have been summarised as the:

- Traceability of information across systems [Štorga et al., 2011, 2009]
- Dependencies between records [Oh et al., 2001, Xu and He, 2004]
- Associating the rationale with the records [Bracewell et al., 2009]
- Duplication and maintaining synchronisation [Hicks et al., 2006]
- Appropriate recording of Engineering Work [Wild et al., 2005]
- Search, retrieval and re-usability of records [Liu et al., 2006]

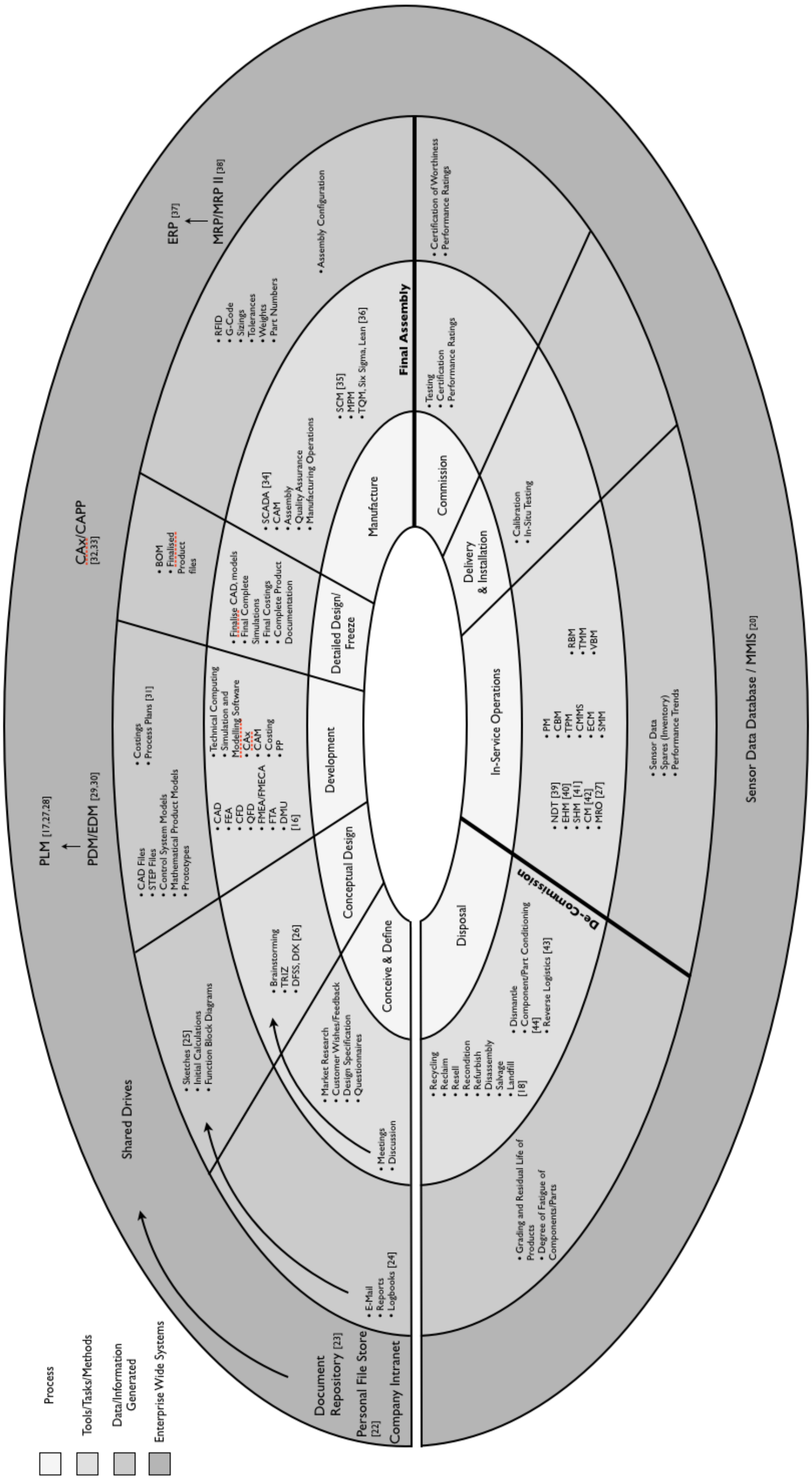


Figure 2.7: Map of the Engineering Information Systems Infrastructure (*From:* Gopsill et al. [2011])

Communication plays an important role in the evolution of Engineering Records as it is well documented that almost all Engineering Design Communication revolve around a record [Eckert and Boujut, 2003, Carlile, 2002, Hicks et al., 2008]. Therefore, many of these contain the rationale that pertain to the evolution of the related record [Regli et al., 2000, Dearden, 2006]. Hertzum and Pejtersen [2000] also shows that communications contain the rationale behind a records re-use. Hence, potentially answering why Engineering Work features a high-level of communication as the engineers need to confirm that the records are re-used appropriately. It is therefore argued that supporting communication has the potential to overcome some of the challenges facing Engineering Records.

This discussion shows that this thesis considers Engineering Records as the data, information and knowledgeable information that is captured and stored across the Product Lifecycle. They can be considered either physical or digital and independent from the process/systems used to create/manage them. Communication contains the rationale behind the evolution and re-use of these records and thus, has the potential to provide significant insights that could be used to overcome the challenges that pose current Engineering Information Systems Infrastructures.

2.5 Engineering Project Management

As defined in the British Standards (BS 6079), Engineering Project Management is '*the planning, monitoring and control of all aspects of a project and the motivation of all those involved to achieve the project objectives on time and to cost, quality and performance*'. Table 2.4 provides a summary of the key milestones leading to this concept of Engineering Project Management. This further highlights that Engineering Project Management concerns the organisation and coordination of teams, and their activities, alongside the monitoring of progress being made [Smith, 2002].

This has led to a wealth of research into best practice in Engineering Project Management and the development of methods, tools and techniques to support Engineering Project Management. For example, Project Evaluation & Review Technique (PERT) and Critical Path Method (CPM) provide methods to structure and map the engineering project ahead of its commencement.

Year	By Whom	Milestone
4000 BC	Egyptians	Demonstrated ability of formally organising and controlling work groups.
1500 AD	Niccolo Macchiavelli	Early explanation of work group structure and functioning
1930's	Sloan, Mayo, Bernard	Formal organization of work groups in bureaucratic, hierarchical structures. Autocratic behaviour.
1950's	Simon, Lewin, Davis, Drucker	Understanding of group dynamics and behaviour in organisations.
1960's	McGregor, Likert, Carzo, Katz, Schein, Lawrence, Lorsch, Jewkes, Blake, Mouton, Fiedler	Translation of established theories from individuals to work groups settings. Increased managerial interest in team building and need for effective team work. Japanese lessons.
1970's	Benningson, Dyer, Kidder	Specific field studies of technical team work. Attempts to characterise drivers and barriers of high team performance.
1980's	Ouchi, Thamhain, Wilemon.	Theory Development

Table 2.4: Key Milestones in Engineering Project Management (*From:* Thamhain and Wilemon [1987])

During a project, techniques such as Six Sigma and Top Quality Management (TQM) look to ensure the quality of processes and products is maintained and potentially improved as the project evolves.

Although numerous methods that have been developed, it has been argued that the majority of project management techniques focus on the management of a project against a static plan. Where milestones and stage-gates are often set to a specific date for when it has to be achieved. New research in this field is now challenging this concept suggesting that traditional milestones & stage-gates can have some dynamism if one were able to monitor and provide insights into the progress of a project in real-time [Hicks, 2013]. For example, monitoring of concept generation could highlight divergence and convergence of ideas, which could indicate when best to perform a design review meeting. A caveat to this is to understand what are the underlying signatures and patterns of activity that could indicate when a project is ready to progress to the next stage or whether a potential issue is arising.

Referring back to communication, it is universally accepted that communication is a fundamental part of coordinating tasks between engineers and groups of engineers, and could also provide additional benefits to the management of an engineering project. Griffin and Hauser [1992] has shown how the communication is indicative of successful product development and, Lusk [2006] & Wasiak [2010] reveal that analysis of the content of communication within a project has the potential to provide patterns and signatures that coincide with project events. This could be of potential use to managers of engineering projects as it could lead to better monitoring of project progress. Leading to targeted and appropriate use of intervention to *steer* the project in an appropriate direction. Supporting Engineering Design Communication has the potential to provide the information required to develop signatures and patterns of Engineering Project behaviour.

2.6 Chapter Summary

This chapter has brought a review of the wider context in which this research sits by describing the terms Engineering Design, Engineering Context, Engineering Work, Engineering Records, and Engineering Project Management. In addition, it has discussed the role that communication has within each given area.

In summary, Engineering Design covers all the aspects that are required in order to generate and develop a product, and is "*fundamentally socio-technical*" where communication is essential. Engineering Design is performed within the wider Engineering Context, which considers the external factors that are placing further challenges on the engineers. These are the need to consider - to an even greater extent - the impact of the product across its entire life cycle, and the need to support the search, retrieval and re-use of past records in an ever-expanding and varied set. This is within an environment that is becoming ever-more distributed and mobile. Leading to the greater use of distributed communication tools that do not currently provide the support required for Engineering Design Communication. Hence, the main gap for potential research.

In addition, communication features heavily in Engineering Work, which pertains to the actual activities performed by the engineers. It provides a crucial role by enabling engineers to share information & knowledge, maintain awareness of project progress and deliver the key outcomes of their activities. Communication also plays an important role in Engineering Records, which covers the data, information and knowledgeable information that is captured and stored across the Product Lifecycle. This is because it is a container for the rationale of a records evolution and how it is re-used. Finally, Engineering Project Management is the organisation, co-ordination of engineering teams as well as monitoring the progression of the project. Monitoring the instances of communication as well as analysing the content of communication has the potential to aid Engineering Project Management.

Chapter 3

Research Methodology

The previous two chapters have provided the context in which this research is based and identified the gap that provided the aim for this thesis.

Aim

To investigate how Social Media can be used to support Engineering Design Communication.

From the previous chapters' review and discussion, it has been made clear that the preferred method of Face-to-Face conversations for Engineering Design Communication is declining due to the increasing distributed nature of Engineering Design. Thus, necessitating the use of tools that have been shown not to provide the support for Engineering Design Communication. To ensure that this does not occur from the output of this research, it is self-evident that one has to consider *what are the requirements for supporting Engineering Design Communication?* before attempting to develop a new method/tool to support communication.

It has already been indicated that Social Media and associated web-based technologies are to be exploited by this thesis in order to fulfil the requirements for supporting Engineering Design Communication. However, it is important to clarify the concept of Social Media and consider how the technologies have been employed. Therefore, it is deemed highly important to ascertain *how can Social Media be used to support Engineering Design Communication?* so that the technologies are deployed appropriately for the given requirements.

By answering the above questions, a method and tool can be developed with the intention to support Engineering Design Communication based on current understanding. As it can only be based upon current understanding, it is crucial that validation and evaluation of the method/tool is undertaken. Alongside this, the previous chapter has highlighted communications influence on many aspects of Engineering Design and it is also important to understand how a method/tool also impacts these areas. Therefore raising the question, *how does Social Media support Engineering Design Communication?*

This reflection of the previous chapters and aim of the thesis leads to its breakdown into three clear Research Questions:

RQ-1: What are the requirements for supporting Engineering Design Communication?

RQ-2: How can Social Media be used to support Engineering Design?

RQ-3: How does Social Media support Engineering Design Communication?

To answer these questions, this chapter discusses and provides reflection upon the methods used in past Engineering Design Communication research and presents the Research Methodology that this thesis adheres to.

3.1 Past Research Methods

In many cases, past research has relied heavily upon the use of questionnaires/-surveys to identify patterns in engineers' communication behaviour or other more qualitative means (Table 3.1) [Tenopir and King, 2004]. These questionnaires are often completed at the '*end-of-day*' so as not to impact on the day-to-day activities of the engineers within the companies. Although convenient, it does require the engineer to reflect upon the entire day and this may be difficult to recall in its entirety, thereby introducing a non-systematic error to the captured information. In addition, the use of questionnaires enables ease in the aggregation of information from participants but can be limiting due to the inability to understand fully '*why*' an engineer decided upon a particular answer on the questionnaire.

Research Data Captured	**Research**
Structured Interviews	Curtis et al. [1988]
Survey	Kraut and Streeter [1995]
Observational	Guinan [1986]
Video Recordings	Walz [1988], Olson et al. [1992]
Audio Recordings	Minneman [1991]
Observation & Interviews	Sonnenwald [1996]

Table 3.1: Examples of Empirical Research (*Adapted from*: Sonnenwald [1996])

Wild et al. [2010] used diary studies to provide an extra dimension into understanding data and document usage of engineers and although it provided interesting insights into engineers' behaviour, there lies inherent risks in generalising the results and in also measuring the completeness of the capture from such a method. Stacey and Eckert [2003] & Baird et al. [2000a] performed ethnographic studies using interviews, video recordings and observations in order to understand communication within engineering. In addition, case studies involving the combination of interviews, questionnaires/surveys and observations have been used to assess the effect of interventions such as the role of Engineering Records in communications [Chiu, 2002, Easterby-Smith and Lyles, 2011, Subrahmanian et al., 2003]. These studies ensure that a wealth of information is captured but requires greater interpretation by the researcher in order to discover correlations and relationships.

Although much of the research has been of a qualitative nature, there has been a few quantitative measures such as Latent Semantic Analysis and the coding of communications [Dong, 2005, Wasiak, 2010]. These have looked at the content of communications and the aggregation of this content across many communications to reveal patterns and relationships within their respective datasets. This type of analysis is often only practically suitable when dealing with large digital datasets such as E-Mail in order to generate any meaningful metrics. With these thoughts in mind, the research approach undertaken by this thesis is presented.

3.2 Research Approaches

Beyond the various qualitative data capture techniques employed by previous researchers in the field, there a number of methodological approaches one can pursue in order to answer the aim of this research. Highlighted here are three potential appraoches one could take; 1) Action Research, 2) the Design Research Methodology and 3) a Design Research Approach. These are now discussed in turn and is then followed by the selected research approach, where a discussion of how it has been aligned to the aim of this research.

3.2.1 Action Research

Defined by Stringer [2013] as:

> “ Action research is a systematic approach to investigation that enables people to find effective solutions to problem they confront in their everyday lives ”

Action research has been employed by many researchers in the field of Engineering Design whereby they are seeking to address a highly-contextually dependent problem. Thus, it is often that case that there are issues in the generalisability of the results produced. Although, the output of such research can be profound in its given context.

It is often referred to as a routine of ‘*look, think, act*’, which is then iterated upon over the period of ones research (Figure 3.1) [Kemmis et al., 2014]. In order to achieve this, the researcher tends to be either directly related to the context of the research (a teacher looking to improve teaching approaches, for example) or enters the given context as a participatory member [Kane and Chimwayange, 2014]. This particular type of methodology has proven incredibly popular with social scientists where one needs to understand the social interactions of individuals in a given context. It is also popular in policy development in fields where experience and knowledge of the area are crucial and is attained over a number of years (i.e. medicine and foreign policy) [Flessner and Stuckey, 2014, OŚullivan and Deb, 2014].

Although this research methodology could be applied to the given context, the research would require a key industrial collaborator in which to study and this was not the case for this research. However, by not catering to a specific engineering collaborator, it provides the opportunity for the research to be more general in its perspective and to potentially increase its applicability across the engineering design field.

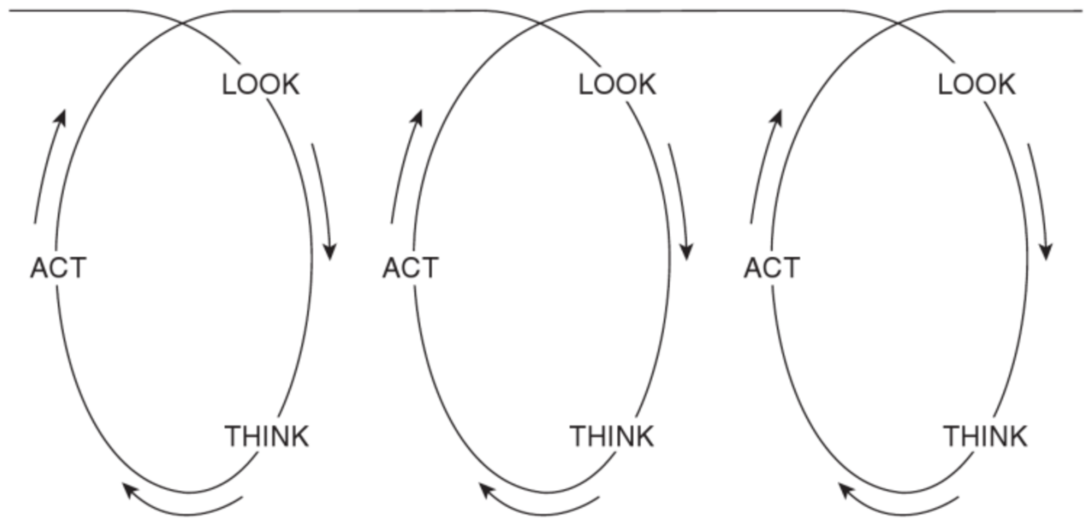


Figure 3.1: Think, Look, Act Iteration Cycle (From: Stringer [2013])

3.2.2 Design Research Methodology

Blessing and Chakrabartis' [2009, p.14-17] Design Research Methodology (DRM) has become a popular methodology to follow within the Engineering Design Research context [Blessing, 1993, Mabogunje, 1998, Stephenson and Wallace, 1995]. They are keen to highlight that design research seeks to understand design so that it can be supported with a view to further improve the design. It's origins stemmed from the research papers in the field not providing a suitable overview of past research, the lack of use of results in practice and the little scientific rigour being imposed on the research methods being used.

The DRM framework is presented in Figure 3.2 and includes four stages; Research Clarification, Descriptive Study I, Prescriptive Study and a Descriptive Study II. Although, the methodology highlights that a researcher can stop at any one of the four stages given they have performed it in a sufficiently rigorous manner. Although for the aim of this research, it is argued that one would proceed through all of the stages stated. This is because one would need to understand the requirements for supporting Engineering Design Communication and how to appropriately apply Social Media techniques in order to meet the requirements. This would form Descriptive Study I. The Prescriptive Study would be where a tool would be developed instantiating the approach derived from the previous reviews of the literature. This would then be used within an engineering project and data recorded on its usage. The results from the Prescriptive Study leads to Descriptive Study II, where a detailed analysis of the results is performed to validate the original requirements drawn from literature and to also evaluate the tool had upon the project in which it was used.

In this manner, this research would follow in a similar vein as the example provided within the DRM book of Blessing [1993] research into 'A Process-based Approach to Computer-supported Engineering Design'. Thus, providing some validity in the use of this method within the given research context.

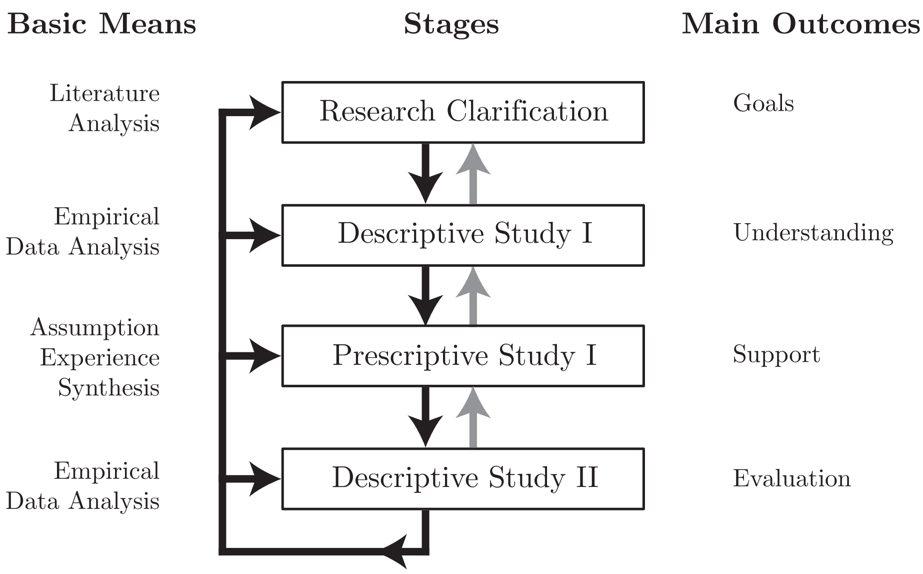


Figure 3.2: DRM Framework (*From*: Blessing and Chakrabarti [2009, p.15], *Re-Illustrated*)

3.2.3 A Design Research Approach

Duffy and O'donnell [1998] design research approach is a relatively new methodology that has been specifically developed for design research. It highlights that design research no longer considers the social interaction and cognition of individuals, but also the information required and supporting computer tools that enable design to occur. They argue that a singular design problem could have a solution in either three of these dimensions and thus, a research methodology that can be deployed irrespective of the dimensions taken would enable research to be compared and contrasted across them.

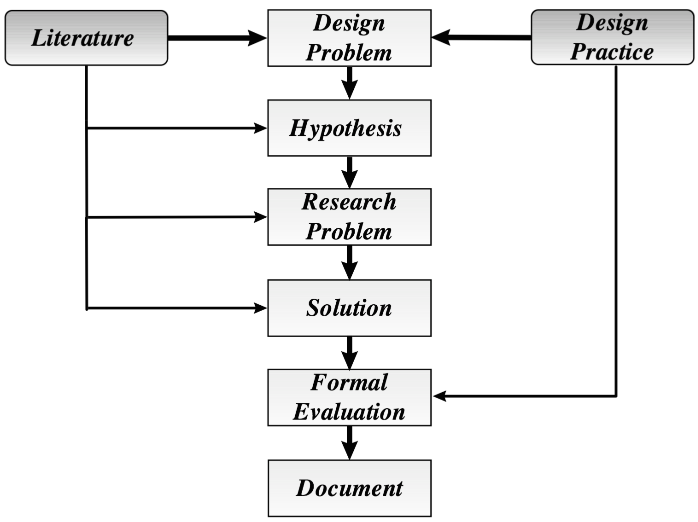


Figure 3.3: A Design Research Approach Methodology (From: Duffy and O'donnell [1998])

A key aspect to the methodology is the need to review literature and to perform some initial studies in the specific context of the research to develop the design problem. It can be argued that this approach very much reflects the full descriptive, prescriptive, descriptive Design Research Methodology cycle. Although, there is an emphasis placed upon the design research to both be validated and evaluated. Validation is where one seeks to address whether the initial hypothesis is true and evaluation is where one measures the impact of the solution provided by the researcher.

Although it makes some interesting points and especially ones with regards to the validation and evaluation aspects of design research, it is argued that the methodology closely resembles the previously discussed Design Research Methodology.

3.3 Selected Research Approach

The research methodology applied in this thesis is Blessing and Chakrabartis' [2009, p.14-17] Design Research Methodology (DRM). The process is one of systematically clarifying the research to be performed and conducting descriptive, prescriptive and descriptive research (Figure 3.2).

The research clarification has already been undertaken in the first two chapters, which describes the context and aim of the research. In keeping with the methodology, a discussion of communication in Engineering Design has been undertaken and the potential in improving the current case highlighted. This has led to the aim of the research, which has been expanded into the previously described Research Questions. Table 3.2 demonstrates how these questions align to the Design Research Methodology and the research methods to be used at each stage are subsequently discussed.

DRM Stage	**Research Question**
Descriptive I	RQ-1: What are the requirements for supporting Engineering Design Communication?
Prescriptive I	RQ-2: How can Social Media be used to support Engineering Design Communication?
Descriptive II	RQ-3: How does Social Media support Engineering Design Communication?

Table 3.2: The alignment of the Research Questions to the DRM Framework

The Descriptive I stage of the process often continues on from the previous review that has clarified the research context, albeit with a more focused literature review of the relevant research [Blessing and Chakrabarti, 2009, p.15]. Therefore, this review has a specific goal to provide the required information to enable the researchers to continue to the Prescriptive I stage. The requirement for this thesis is to understand *what are the requirements for supporting Engineering Design Communication?* Such is the breadth and wealth of research that is related to Engineering Design Communication, which has also, consistently reflected similar results, it has been deemed appropriate to perform a review of the Engineering Design Communication literature to elicit and synthesise these requirements.

Using these requirements and increased understanding, the researcher is able to proceed to the Prescriptive I stage of the framework [Blessing and Chakrabarti, 2009, p.16]. This is where the researcher proposes how one can improve the current situation. In this case, this thesis answers Research Question Two; *how can Social Media be used to support Engineering Design Communication?* This is again achieved by a review of the literature regarding the concept of Social Media as well as identifying best practice in applying web-based technologies, whereby a set of considerations can be elicited when taking a SM approach. This is coupled with the previously established requirements for supporting Engineering Design Communication and enables the proposition of a Social Media approach to support Engineering Design Communication. This Social Media approach describes how the technologies should be used to enable engineers to communicate alongside its management. To assess the impact of the Social Media approach, a custom-built tool known as PartBook is developed iteratively and a Small-to-Medium Enterprise in Bath agreed to assess the tool during its development as well as being used for a questionnaire to provide insights into their current communication practices.

The Descriptive II stage of the framework requires the researcher/s to assess the impact of their proposition on an engineering project [Blessing and Chakrabarti, 2009, p.16]. As previously stated in section 2.3, the impact of the research is how it furthers scientific knowledge as well as its practical significance. In the case of this thesis, this comes as:

1. Validation of the requirements & considerations generated from Descriptive I & Prescriptive I.
2. Evaluation of the tool through discussion of its impact on the engineering project it is has bee implemented in.

Although the tool was presented to a number of engineering companies[1], none were willing to trial it within their company as it is a prototype and posed too much of a risk to a critical part of their business without seeing results from an initial trial. Therefore, PartBook has been implemented into a Formula Student engineering project at the University of Bath. The Formula Student project provides the most resemblance to an industrial project (described in more detail in Chapter 8) and is the largest engineering project run at the University and is both multi-disciplinary and distributed. This study is of the Real-World (i.e. not contrived) and therefore, Robson [2002] highlights the importance of the research to assess the impact of the implementation in as much breadth as possible and to have a flexible strategy as there are many outside influences. McAlpine [2010] has aligned the key points made by Robson [2002] on Real-World Research with respect to measuring the impact of Engineering Design research. The seven points are summarised in Table 3.3 alongside how it has been addressed by this research. Considering this, a multiple methods of data capture is used during the study and provided a dataset containing the; e-mail communications, PartBook communications and user activity, feedback sessions and questionnaires. The importance of functionality vs usability of the tool is also a factor that has been considered through the systems usability scale [Bangor et al., 2008, Sauro, 2011] . From this, the study has been able to evaluate and validate the requirements to support Engineering Design Communication, thereby closing the loop. Also, it looks at *how does Social Media support Engineering Design Communication?* with respect to Engineering Work, Records and Project Management through analysis of the dataset.

[1] Airbus, Volvo Aero and Bath Institute of Medical Engineering (BIME)

Summarising Points on Real-World Research	**Implication on Research Performed**
1. Rigorous data collection, using multiple methods. Data are summarised (e.g. in tabular form). Detail about how data are collected is recorded.	Data has been collected through feedback sessions, surveys and capture of communications within the tool, e-mails and engineering records on a shared drive space.
2. The study is framed within the assumptions and characteristics of the flexible (qualitative) approach to research. This includes fundamental characteristics such as an evolving design, the presentation of multiple realities, the researcher as an instrument of data collection and a focus on participants' views.	The development of the tool has gone through iterative development and feedback from industry as well as meeting requirements developed from literature.
3. The study is informed by an understanding of existing traditions of enquiry; i.e. the researcher identifies, studies and employs one or more traditions on enquiry. This tradition need not be 'pure', and procedures from several can be bought together.	The research is an application of the DRM methodology and use of Formula Student as a study has been performed before in the field.
4. The project starts with a single idea or problem that the research seeks to understand, not a causal relationship of variables or a comparison of groups (for which a fixed design might be indicated). Relationships might evolve or comparisons might be made, but these emerge later in the study.	The introduction and literature review has developed the research aim, which is the single idea that this research seeks to understand.
5. The study includes detailed methods, a rigorous approach to data collection, data analysis and report writing. The researcher has the responsibility of verifying the accuracy of the account given.	Dedicated sections and chapters within the thesis provide detail on the capture methods and study context.
6. Data are analysed using multiple levels of abstraction. Often, writers present their studies in stages (e.g. multiple themes that can be combined into larger themes or perspectives), or layer their analyses from the particular to the general.	The study has been analysed to validate, evaluate and assess the potential impact of supporting Engineering Design Communication using a Social Media Approach.
7. The writing is clear, engaging, and helps the reader to experience 'being there'. The story and findings become believable and realistic, accurately reflecting the complexities of real life.	

Table 3.3: Considerations in ensuring a flexible Research Strategy (*Adapted from* Robson [2002] *by* McAlpine [2010])

3.4 Research Plan

Although there has been a discussion with regards to how the research aligns to the Design Research Methodology, it is also useful to provide a pragmatic breakdown of the research in relation to the process one would follow during the three year time period. Figure 3.4 presents the research project plan and highlights that there are two main themes of review at the beginning of the study that have run concurrently. These are both the development of an understanding in relation to Engineering Design Communication and Social Media. The requirements elicited and synthesised from Engineering Design Communication literature and the considerations elicited and synthesised from Social Media literature are then brought together in order to develop the Social Media Approach. This has then been instantiated within a tool that enables user driven validation to occur. In addition, a secondary analysis of the use case provides the results to understand how Social Media can be used to support Engineering Design Communication.

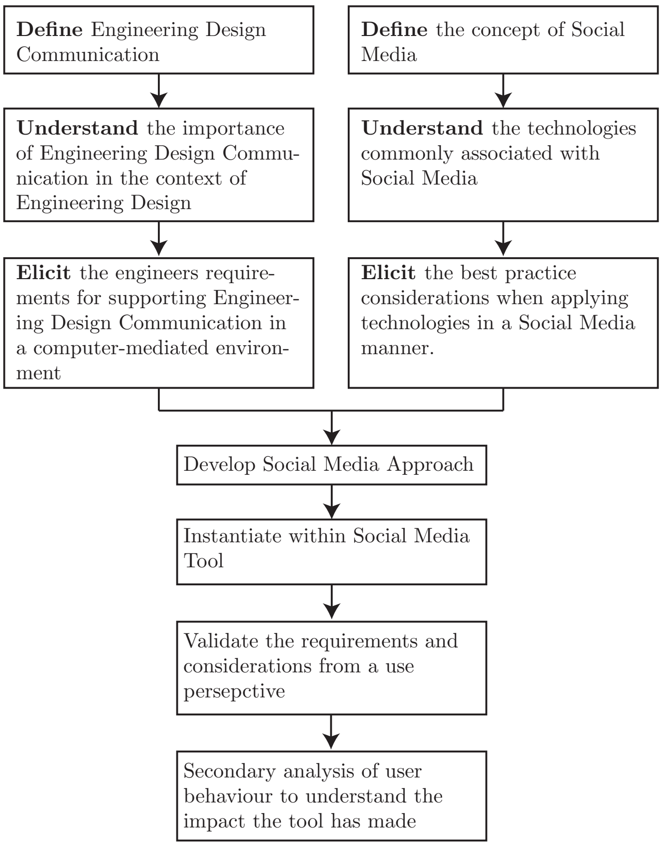


Figure 3.4: Research Project Plan

In addition to the pesearch project plan, a research project time-line is provided (Figure 3.5). This again shows the concurrency within the research presented and also highlights the development of the skill set required to produce a tool that suitably reflects the Social Media Approach, which has been derived from the review of the two areas of literature. In addition, the Figure highlights the main purpose of the GDBP and SME studies in testing the usability of the tool that was in development. The Formula Student study is where the validation and evaluation of the final tool instantiating the Social Media tool took place.

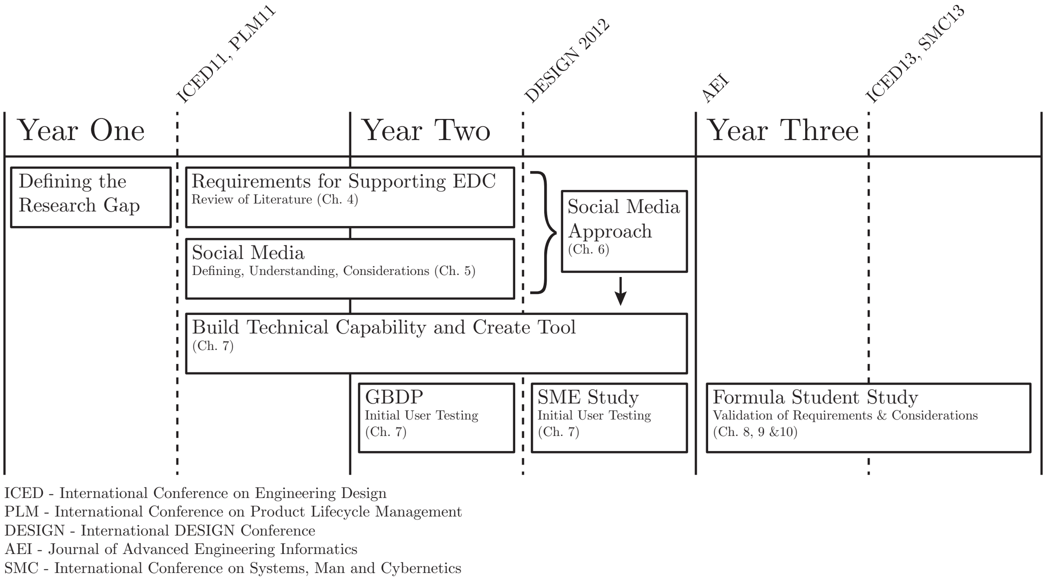


Figure 3.5: Research Project Work Package Timeline

3.5 Chapter Summary

This chapter has discussed the Research Questions that need to be answered to achieve the aim of the thesis, presented an overview of the research methods employed by past studies in the field of Engineering Design Communication and has subsequently discussed the Research Methodology that this thesis adheres to. This has been the Design Research Methodology by Blessing and Chakrabarti [2009] and Table 3.4 provides a summary of how the research presented here aligns to it. In addition a research plan show the pragmatic view of how the research aligned to the three-year timescale. Finally, the importance of having a flexible Research Strategy when performing research in the Real-World has been discussed alongside implications it has made to ensure the validity and re-usability of the research.

DRM Stage	Research Question	Research Method(s)	Chapter(s)
Research Clarification	n/a	Review of Research Concerning Engineering Design Communication and its impact on Engineering Design, Records, Project Management & Work	1 & 2
Descriptive I	What are the requirements for supporting Engineering Design Communication?	Elicit and synthesise requirements from a review of the literature.	4
Prescriptive I	How can Social Media be used to support Engineering Design Communication?	A review of literature to elicit the appropriate deployment of the technologies underpinning Social Media to support communication. A proposed Social Media approach to support Engineering Design Communication culminating in a tool known as PartBook. This has been iteratively developed with the aid of a study with an SME in Bath.	5, 6 & 7
Descriptive II	How does Social Media support Engineering Design Communication?	Analysis of the impact of PartBook within a Formula Student project with respect to evaluating & validating the requirements and potential affordances to Engineers' Work, Records and Project Management. The study employs multiple methods of data capture.	8, 9 & 10

Table 3.4: Research Methodology for the Thesis

Chapter 4

The Requirements for Supporting Engineering Design Communication

As previously stated, there is a wealth of descriptive research relating to Engineering Design Communication. Therefore, this thesis builds upon the literature by eliciting and synthesising the requirements for supporting Engineering Design Communication in order to answer RQ1.

What are the requirements for the supporting Engineering Design Communication?

Some one hundred research documents from key sources in the fields of Engineering Design, Professional Communication, Knowledge & Information Management, Computer-Supported Collaborative Work and Project Management have been reviewed. Table 4.2 provides an overview of the various engineering disciplines that the review includes. the papers are referenced throughout this chapter and the requirements are also highlighted during the review. Due to the size of the review, the literature has been grouped into four distinct areas and the focus is upon how communication relates to these areas (Table 4.1). It is also important to note that this review only considers the requirements from supporting Engineering Design Communication and it is recognised that there would be additional company requirements that a tool would have to meet.

Section 4.1: Engineering Records	Where the review looks at the relationships between Engineering Design Communication and Engineering Records.
Section 4.2: Engineers' Work	Where the review looks at the relationships between Engineering Design Communication and Engineers Work.
Section 4.3: Its Purpose and Evolution	Where the review looks at why a communication episode arises and how it evolves over time.
Section 4.4: The Engineering Context	Where the review looks at how Engineering Design Communications align themselves to the Engineering Design Context.

Table 4.1: The Structure of the Review

Field	**Related Papers**
Review & Theory	Sim and Duffy [2003], Leckie et al. [1996], Daft and Lengel [1986], Gopsill et al. [2011], Clarkson and Eckert [2005], Smith [2001], Tenopir and King [2004], Wang et al. [2002]
Contrived Design Experiments	Gero and Neill [1998], Stempfle and Badke-Schaub [2002], Subrahmanian et al. [2003]
Aerospace	McAlpine et al. [2006], Ahmed and Wallace [2004], Lowe et al. [2004b], Aurisicchio et al. [2010], Baird et al. [2000a]
Automotive	Boujut and Blanco [2003], May and Carter [2001], Štorga et al. [2011]
Manufacture	Ullman et al. [1996], Adler [1995], Chungoora and Young [2011], Toye et al. [1993]
Civil/Architecture	Luck [2007], Perry and Sanderson [1998], Zurita et al. [2008]
ICT	Allard et al. [2009], Nardi et al. [2000], Hertzum and Pejtersen [2000]
Marine	Wasiak et al. [2011]
Industrial Engines	Henderson [1991]
Textiles	Eckert et al. [2001]
Buyer-Supplier Relationships	Höllta [2011]
Exhibition Design	Lee [2007]
Various	Carlile [2002], Hicks et al. [2008], Heisig et al. [2010], Ellis and Haugan [1997], Milne and Leifer [2000]

Table 4.2: Engineering Fields Featured in the Review

4.1 Engineering Records

> "Here, sketching and drawing are the basic components of communication; words are built around them, but the drawings are so central that people assembled in the meeting wait while individuals fetch visual representations left in their offices or sketch facsimiles on white boards"
>
> Henderson [1991]

Almost all communications revolve around an Engineering Record[1] [Eckert and Boujut, 2003, Carlile, 2002, Hicks et al., 2008]. Records can be either digital/physical and include, sketches, calculations, Computer Aided Design (CAD) files, simulation set-ups/results, reports, prototypes and the products/parts (Table 4.3 provides a more complete list although not intended to be exhaustive). These have been created during the Product Development process to describe and represent the product and its process of manufacture. The effectiveness of the communication centres around the engineers ability to use records to help externalise the problem/issue/query/statement they wish to make [Boujut and Blanco, 2003, Ullman et al., 1996, Delinchant et al., 2002]. Having the records associated with the communication also reduces equivocality during its evolution [Adler, 1995, Daft and Lengel, 1986]. It can be considered that the use of Engineering Records has the ability to either explicitly or implicitly represent the 'focus' of the communication and/or provide the context necessary to describe it. This is especially apparent in multi-disciplinary environments [Subrahmanian et al., 2003]. Table 4.3 also summarises possible foci of the records with regards to the communication (and is discussed later). Luck [2007] also highlights that records are able to help achieve a '*common*' understanding between the engineers due to their familiarity with them. Thus, it can be considered crucial to be able to include the record/s alongside any communication.

High-Level Artefact Types	**Focal Points**
Sketch	Aesthetics, Alternatives, Force Diagram, Operation
Engineering Drawing	Dimensioning, Tolerancing
Computer Aided Design	Dimensioning
(CAD)	Tolerancing, Mating, Error Message, Protrusion
Computational Fluid Dynamics (CFD)	Mesh, Results,Run-Time Error, Set-Up
Simulation	Code, Error Message
Finite Element Analysis (FEA)	Mesh, Results, Run-Time, Set-Up
(Physical) Product	Maintenance, Manufacture, In-Service
(Physical) Part	Manufacture, In-Service, Maintenance
Calculation	Stress, Force, Vibration
(Physical) Assembly	Maintenance, Manufacture, In-Service
Prototype	Function, Feature, Ergonomics, Aesthetics
Report	Abstract, Results, Outline, Conclusion

Table 4.3: Example Artefacts and Focal Points

[1] Also referred to as Artefacts, Intermediary or Boundary Objects, or Digital Assets.

However, this may be difficult through the need to support distributed communication through a computer-mediated tool as the records may be considerably large digital files or an actual physical object. In addition, Gopsill et al. [2011] reveals the complexity and number of information systems currently used to handle wide variety and diversity of Engineering Records and therefore, the sharing of all types of Engineering Record alongside the communication can be considered currently implausible.

Although, a representation of the record (i.e. an image) can provide almost all of the benefits of the actual record [Heisig et al., 2010]. In particular, the representation still contains the required context for an engineer to be able to interpret the statement being made. This would suit the ubiquity required for a distributed computer-mediated tool, although it has been noted that these representations should be of a high quality to prevent confusion [May and Carter, 2001]. An additional affordance is that it enables the capture of the temporal state of the record. Thus, upon viewing the communication in the future, the engineers are able to interpret the communication in the same manner although the actual record may have evolved since.

Henderson [1991] reveals that one record is often at the centre of the communication. Additional records presented at the beginning of the communication can lead to greater confusion. Although, as engineers contribute to communications, they often use additional records to either support their statement, present potential changes that could be made, or show the effect of changes to the record. Zurita et al. [2008] reveals that the ability to represent changes to the record aids collaborative design as engineers are better able to understand the meaning behind the words being used by others. From this discussion, three requirements are synthesised; 1) to capture a high quality representation of the central record relating to the communication, 2) to record changes to the record as a consequence of the communication and 3) to enable contributing engineers to embed a representation of a record in their responses within a communication episode.

Referring back to Table 4.3, it can be seen that there is potentially an inexhaustible list of records and corresponding '*focal*' points. Huet et al. [2009], McAlpine et al. [2006] & Hicks et al. [2008] highlight that there needs to be a textual description of the record in order to be able to search, retrieve and aggregate communications. Explicitly capturing the record type in the form of text prevents ambiguity in the mind of an engineer participating within a communication [Eckert and Boujut, 2003]. This leads to a fourth requirement 4) to provide a text based description of the artefact, as demonstrated in Table 4.3.

The '*focal*' point is defined as the subject of interest pertaining to the record [Perry and Sanderson, 1998, Gero and Neill, 1998]. As shown in Table 4.3, '*focal*' points can vary between records and although a list has been developed, it is not exhaustible and is likely to continually evolve. This is due to ever-changing areas of interest for the engineers as progress is made during Product Development [Chungoora and Young, 2011]. Lee [2007] supports this by discussing how records are defined by their use and this can change over time. Thus, it is argued that the '*focal*' point is crucial in aiding engineers to interpret the record effectively within the context of a communication. This leads to a fifth requirement 5) to record/capture the foci of a communication with respect to the record.

Although a representation of the record can perform in almost the same manner as the actual record within the communication, it is argued that there is still benefit in being able to refer to the actual record, (particularly if electronic,) by capturing its location (for example, a URL of the file). This could enable engineers participating in the communication to effect changes to the record as the communication evolves. In addition, it provides a means to integrate communication records with the companies information systems infrastructure. There is also potential in terms of re-use, as it will enable the association of design rationale to the record to which it pertains. Therefore, it may further aid understanding into the evolution of Engineering Records during Product Development [Pavkovi et al., 2010]. This gives rise to a sixth requirement 6) to provide an electronic or physical reference to the Engineering Record.

4.2 Engineers' Work

As previously discussed, engineers prefer to seek information through informal communication channels and it can be seen that communication is intrinsic to Engineers Work [Ellis and Haugan, 1997, Wood and DeLoach, 2001]. Höllta [2011], Clarkson and Eckert [2005], Maier et al. [2006] & Maier et al. [2008] highlight that a major contributing factor to poor communication is the lack of '*awareness*', where engineers are unable to contribute due to not knowing of the existence of a communication or due to restrictions within company practices (i.e. confidentiality and/or project team segregation). The consequence of this is that the most appropriate engineers may not be contributing to the relevant communications. Thus, it is considered crucial to support engineers in directing their communications as well as highlighting communications that they could potentially participate in.

Milne and Leifer [2000] & Zipperer [1993] show that engineers make considerable use of their own social knowledge to ensure communications are sent to (and received by) the right engineers. In addition, using fellow engineers to provide the engineer with the right contacts is often the '*quickest*' - in terms of time, ease to do so and least effort - route to satisfy their communication needs even when compared to modern day search tools [Allard et al., 2009]. Tenopir and King [2004] are advocates of the concept of engineer '*stars*' and '*gatekeepers*'. These are engineers that receive the majority of the communications, who then forward them to those that are best placed to respond. Thus, there is an argument for the requirement to provide functionality that enables engineers to push communications to one another and therefore take advantage of the inherent engineers' social knowledge within the project. Therefore, the seventh requirement is 7) to enable engineers to '*push*' communications to one another.

Adler [1995] describes how some engineering companies are now forming task groups for specific purposes, which then disband once the task is complete in order to better manage the human resources. This is alongside teams that are focused upon a particular expertise and contain deep domain knowledge, These are commonly referred to as core competency groups. Thus, there is a need to support communications associated with group work and to ensure that all engineers within a group are aware of potentially relevant communications. Likewise, there should also be functionality to ensure engineers are able to indicate relevant core competency groups so that they are made aware and able to respond to the communication. Additionally, McAlpine et al. [2006] discuss the importance of engineering logbooks and the need for personal bookmarking, as it enables quick referral to important/key resources to support work and activities. These findings lead to three further requirements: 8) to enable engineers to group communications by tasks, 9) to solicit responses from core competency (expert) groups and 10) to enable engineers to assign personal bookmarks to communications.

4.3 Its Purpose and Evolution

This section considers the creation, response and output of communications, alongside the reasoning behind why it is necessary to support this within a computer-mediated environment. As mentioned previously, Engineering Design Communication research is potentially reaching a plateau of understanding with much knowledge on *why* engineers wish to communicate but limited understanding of *how* engineers respond, conclude and possibly refer back to communications. In light of this, logical propositions are made where gaps exist to the support of the evolution of the communication within a computer-mediated environment.

4.3.1 Purpose of Communication

Although current communication channels have the potential to permit more than one purpose to be expressed within a single communication, Wasiak et al. [2011], Maiden and Bright [1996], Aurisicchio et al. [2010] & Gopsill et al. [2013a] suggest that communications almost always have one main purpose. Examples include, idea generation, highlighting an issue, asking clarification, requesting information and making a comparison. Table 4.4 presents ten purposes of communication identified within the literature.

Purpose of Communication	**Description**	**Reference**
1. Idea	The engineers wants to show something potentially new	Milne and Leifer [2000], Wasiak et al. [2011]
2. Help	The engineer wants to solve a process problems	Ahmed and Wallace [2004]
3. Issue	The engineer wants to solve a product problem	Wasiak et al. [2011], Ahmed and Wallace [2004]
4. Clarification	The engineer wants to double-check their knowledge on a subject	Baya and Leifer [1995], Wasiak et al. [2011], Milne and Leifer [2000], Ahmed and Wallace [2004], Perry and Sanderson [1998]
5. Observation	The engineer wants to highlight an record of potential interest	Wasiak et al. [2011], Ahmed and Wallace [2004]
6. Confirmation	The engineer wants to ensure the record is correct	Aurisicchio et al. [2010], Milne and Leifer [2000]
7. Comparison	The engineer wants to converge upon a solution	Aurisicchio et al. [2010], Baya and Leifer [1995], Eckert et al. [2001]
8. Option Generation	The engineer wants to generate a number of solutions to a problem	Aurisicchio et al. [2010], Eckert et al. [2001]
9. Information Request	The engineer wants to locate/receive information with regards to a particular subject	Baya and Leifer [1995], Wasiak et al. [2011], Aurisicchio et al. [2010], Milne and Leifer [2000], Ahmed and Wallace [2004]
10. Decision	The engineer wants to propose a decision that they have made and want other engineers' input	Toye et al. [1993], Eckert et al. [2001]

Table 4.4: Types of EDC Identified by the Literature

Understanding the purpose and inherent context of the communication is expected by all engineers contributing to the communication without the need to explicitly describe it during the exchange of statements [Henderson, 1991]. Ensuring that this context is available to the engineers is crucial for generating a '*common*' understanding within a communication episode. Not achieving a '*common*' understanding often leads to communication breakdown where the goal set-out is not achieved. It can also be a source of frustration for engineers and leads them to cease contributing. The likelihood of this occurring increases within a computer-mediated environment. Therefore, there is a need to explicitly capture the purpose of the communication in order to reduce the likelihood of communication breakdown by ensuring that engineers know what to expect from the communication [Lowe et al., 1999, Leckie et al., 1996]. Capturing the purpose of communication also has benefits in enabling engineers to identify the communications that they are able to contribute to, as well as providing a method by which the communications can be aggregated. This could potentially lead to the identification of patterns in the purposes during the product development process. This leads to the eleventh requirement for the engineer 11) to define the purpose of the communication (e.g. Table 4.4).

4.3.2 Types of Response

Engineers make considerable use of mannerisms and expressions to infer their thought process and provide the perspective of '*where they are coming from*' when they respond during a communication episode [Sim and Duffy, 2003]. This is one reason why Face-to-Face is often still preferred [Nardi et al., 2000]. Again, this would have to be elicited within a computer-mediated environment and may be of even greater importance when one considers that the engineers contributing to the communication may not know each other socially [Hertzum and Pejtersen, 2000, Smith, 2001]. Table 4.5 represents a list of response types that have been synthesised from the literature. However, the extant research has often employed surveys/interviews with a primary focus on analysing the purpose of the communication. Research on how a communication evolves and the types of responses used is therefore limited, thus the aggregation of current understanding has been made alongside proposed positive/negative response types. This has been typically used in Design Rationale tools and therefore it is argued that the engineers will have a familiarity with this concept. This synthesis has revealed thirteen types of response.

Type of Response	**Description**	**Reference**
1. Opinion	The engineers wants to provide their own personal view upon the communication	Baird et al. [2000b], Jonassen and Kwon [2001], Al-Rawas and Easterbrook [1996], Allard et al. [2009], Eckert et al. [2001], Larsson et al. [2002], Höllta [2011], Poltrock et al. [2003], Huet et al. [2007], Wasiak et al. [2011], Bergstrom [2007], Hertzum and Pejtersen [2000], Bellotti and Bly [1996]
2. Experience	The engineer wants to express a view based upon their own experience	Milne and Leifer [2000], Leake and Wilson [2001], Schneider et al. [2008]
3. Observation	The engineer wants to show an artefact of potential interest to the communication	Milne and Leifer [2000], Wasiak et al. [2011], Ahmed and Wallace [2004]

Type of Response	Description	Reference
4. Guidance	The engineer wants to express something that the engineer should consider	Rupprecht et al. [2000], van der Kleij et al. [2009], Ahmed and Wallace [2004], Eckert et al. [2001]
5. Action	The engineer wants to inform the engineer on what he/she has to do	May and Carter [2001]
6. Idea	The engineer wants to introduce something potentially new to the communication	Milne and Leifer [2000], Wasiak et al. [2011]
7. Affirmative	The engineer wants to acknowledge a statement that has been made	(+)
8. Location	The engineer wants to provide the location of some potentially useful information	Eckert et al. [2001]
9. Agree	The engineer wants to express a positive stance on an existing statement within the communication	(+)
10. Disagree	The engineer wants to express a negative stance on an existing statement within the communication	(–)
11. Warning	The engineer wants to highlight area/s to be wary of	
12. Valid	The engineer wants to highlight a valid statement without positioning themselves	(+)
13. Not-Valid	The engineer wants to highlight and provide a reason for a invalid statement and again, not to position themselves	(–)

Table 4.5: Response Types Identified within the Literature

Dong [2005] highlights that the best communications are where engineers achieve a '*common*' understanding and are able to express themselves coherently. Therefore, it is argued that enabling engineers to indicate their response type will increase the coherence of the communication. In addition, this may provide further understanding into how communications evolve during product development and may lead to the identification of patterns associated with successful communications and communication breakdown. Therefore, this is instilled as the twelfth requirement; for the engineer 12) to define the type of response for each contribution to the communication (e.g. Table 4.5).

Stempfle and Badke-Schaub [2002] also highlight that it is important for engineers to provide clear intent when they contribute to communications. Although, they also warn that it would be '*foolish*' for a system/process to attempt to structure the communications. However, there is a case for ensuring communications '*stay on the right track*', hinting that semi-structuring communications may help. Perry and Sanderson [1998] concluded that there should be response size limitations to reduce the chances of '*waffle*' and maintain conciseness. Referring back to the purposes of communication and response types, it is argued that certain response types align themselves better to different purposes of communication and therefore in an attempt to ensure engineers maintain focus upon the communication, this thesis presents a matrix of which types of response should be associated with each purpose of communication (Table 4.6). This discussion give rise to two further requirements; 13) to align the response types to the appropriate purposes as demonstrated in Table 4.6 and 14) to ensure an appropriate limit is imposed on the size of a response.

The final aspect of the responses of communication is due to the increasingly collaborative

		Purpose of the Communication									
		Idea	Help	Issue	Clarification	Observation	Confirmation	Comparison	Option Generation	Information Request	Decision
Response Types	Opinion	■	■	■	■	■	■	■	■	■	
	Experience	■	■	■	■	■	■	■	■	■	
	Observation	■	■	■	■	■		■	■		
	Guidance	■	■	■	■	■					
	Action	■	■	■	■	■					
	Idea	■		■		■			■		
	Affirmative	■	■	■	■	■					
	Location	■	■		■					■	
	Agree						■				■
	Disagree						■				■
	Warnings		■	■	■						
	Valid						■				■
	Not-Valid						■				■

Table 4.6: Purpose and Response Types Association Matrix

and multi-disciplinary working environment [Eckert et al., 2001, Baird et al., 2000b]. It is often the case that engineers from different disciplines will look at a problem from different perspectives and may develop different solutions. During Face-to-Face communications, this divergence and convergence of ideas/perspectives to achieving the purpose of the communication can occur. However, this is very difficult to achieve with tools such as E-Mail. Sim and Duffy [2003] & Cross et al. [1996] show that there are a considerable number of activities where divergence and convergence is essential and thus, it can be seen that it is important to enable engineers to have multiple threads within a single communication. Thereby, providing the ability to direct responses to the right places within the communication. This is particularly important given the often asynchronous nature of computer-mediated communication as this direction and flow of communication could be lost. This leads to the following requirements; 15) to enable multiple-threads within a single communication episode (divergence) and 16) to enable engineers to respond to one or more threads within a communication using a single response (convergence).

4.3.3 Closing a Communication and Re-Use

For the purpose of supporting communication through both use and re-use, it is self-evident that there is a need to determine the result of a communication. Given that the communication process is created by an engineer or group of engineers, it is proposed that they should also determine the result of the communication. The end of Face-to-Face communication is often clear in the minds of the contributors but cannot ever be viewed by future engineers. Although, the potential for the re-use of communications can be seen by the fact that engineers often archive potentially useful E-Mails. However, constraints on the storage capacity often placed by companies limits the potential for such re-use. Therefore, it is argued that the current application of communication tools has almost solely focused on supporting the use state and thus, provide limited capacity to support re-use. A logical proposal is to assume that there is either a positive or negative outcome (similar to pros/cons used by Bracewell et al. [2009]), and in a computer-mediated environment, the communication may not even receive a reply. Therefore, this thesis proposes the following conclusion types for the purposes of communications (Table 4.7).

Communication Type	**Conclusion Type**
Idea	Good Idea: Pursued (+ & consequence)
	Good Idea: Did Not Pursue (+ & consequence)
	Not Plausible (–)
	Already Conceived
Help	Resolved: Process Lesson Learned (+)
	Unresolved;: Possible Process Issue (–)
Issue	Resolved: Product Lesson Learned (+)
	Unresolved: Possible Product Issue (–)
Clarification	Clarified (+)
	Not Clarified (–)
Observation	Artefact of Interest (+)
	Non-Consequential
	Good Work (+)
	Seen Before (–)
	Possible Issue (–)
Confirmation	Yes: All Good (+)
	No: Amendments Required (–)
	No Confirmation (–)
Comparison	Option Selected (+)
	No Options Selected (–)
	Hybrid Option (+)
Option Generation	Options Generated (+)
	Lack of Options (–)
Information Request	Received: Useful Information (+)
	No Useful Information Received (–)
	Lack of Information (–)
Decision	Decision Made (+)
	No Decision Made (–)

Table 4.7: Proposed Conclusion Types of Engineering Design Communications

Each purpose has its own individual conclusion types. Capturing the positive/ negative conclusion may provide a useful insight into whether there is a pattern in the evolution of the communication and the resultant conclusion type. In addition, it may provide a useful index measure for the search & retrieval of communications for future engineers. This leads to a seventeenth requirement 17) to formally conclude a communication (e.g. Table 4.7).

Now that the communications are to be stored, there is a need to consider how the communications can be re-used. Štorga et al. [2011] discuss the importance of traceability throughout an engineering system and how it further enables engineers to understand the evolution of past product developments. Königs et al. [2012] concludes that communication is a key link that can achieve traceability and be used to determine dependencies between Engineering Records. As engineers often refer back to past designs, experience and events to provide reasoning for their statements, it is argued that engineers need to be able to link communications together through the statements they make, thereby using past communications as supporting evidence. In addition, this would provide traceability of knowledgeable information and would be highly useful in understanding how previous communications affect future outcomes. This leads to an eighteenth requirement 18) to enable engineers to reference responses in past communications in current communications.

As well as referral to past communications during new communications, the viewing of past communications can occur and engineers may find value in re-using these communications. To further understand the value of the stored communications, it is proposed that there should be functionality to enable engineers to comment on past communications. This can be thought of as hindsight as it provides information on how the communication was re-used. Table 4.8 highlights potential reasoning for commenting on a past communication. This leads to the requirement 19) to enable engineers to comment on past communications (e.g. Table 4.8).

Comment Type	**Description**
Re-Used	The communication has been re-used in a future unforeseen purpose and the engineer describes how it has been re-used.
Redundant	The communication is no longer of use to the company and the engineer explains why it now no longer of use.

Table 4.8: Types of Commenting on an Engineering Design Communications

4.4 Engineering Context

Hicks et al. [2002] & Grebici et al. [2009] both highlight that the capture of contextual information is critical to enabling use and re-use of information within engineering. Wasiak et al. [2011] & Sonnenwald [1996] mention three common dimensions that align the communication to either the Company, Product, Product Lifecycle, or a combination thereof. Including these dimensions during the creation of a communication will aid the search & retrieval of communications by engineers [Leckie et al., 1996, Lowe et al., 2004b, Wang et al., 2012]. Ahmed and Wallace [2004] show that the inclusion of more dimensions enables novice engineers to search and retrieve information more easily. Finally, Wang et al. [2002] shows that additional contextual dimensions reduces the uncertainty and '*fuzziness*' of the communication, as the alignment to the Engineering Context has been explicitly made. Therefore, this leads to the final requirement 20) to classify communications by the Company, Product and phase of the Product Lifecycle.

4.5 Chapter Summary

This chapter has elicited and synthesised the requirements generated from the review of the literature (Table 4.9). A total of twenty requirements have been elicited from the research relating to Engineering Design Communication, which has revealed the relationships between communications and Engineering Records, Engineers' Work, its own purpose and evolution, and the Engineering Design Context.

Requirement No.	**Requirement:**
1	To capture a high quality representation of the originating Engineering Record relating to the communication.
2	To record changes to the Engineering Record as a consequence of the communication.
3	To enable contributing engineers to embed a representation of an artefact in their responses.
4	To provide a text based description of the Engineering Record (Table 4.3).
5	To record/capture the foci of a communication with respect to the Engineering Record (Table 4.3).
6	To provide an electronic or physical reference to the Engineering Record.
7	To enable engineers to 'push' communications to one another.
8	To enable engineers to group communications by task.
9	To enable engineers to solicit responses from core competency (expert) groups.
10	To enable engineers to assign personal bookmarks to communications.
11	To define the purpose of the communication (e.g. Table 4.4).
12	To define the type of response for each contribution to the communication (e.g. Table 4.5).
13	To align the response types to the appropriate purposes (Figure 4.6).
14	To ensure an appropriate limit is imposed on the size of a response.
15	To enable multiple-threads within a single communication episode.
16	To enable engineers to respond to one or more threads within a communication using a single response.
17	To formally conclude a communication (e.g. Table 4.7).
18	To enable engineers to reference responses in past communications within current communications.
19	To enable engineers to comment on past communications (e.g. Table 4.8).
20	To classify communications by the Company, Product and phase of the Product Lifecycle.

Table 4.9: Summary of the Requirements Elicited from EDC Literature

Chapter 5

Considerations in Developing a Social Media Approach

Since RQ-1 has been answered through the development of the requirements for the support of Engineering Design Communication in the previous chapter, it is now appropriate to focus upon RQ-2 and therefore, the prescriptive element of the DRM framework.

How can Social Media be used to support Engineering Design Communication?

It is important to note that Social Media is not simply the application of Information Communication Technologies. Rather, it is a concept of how these technologies should be applied in order to support communication between the users of a given community. Thus, this concept needs to be discussed in order to understand whether the support of Engineering Design Communication can be achieved. In addition, it is accepted that many Social Media tools are web-based and that they do provide similar functionality. Therefore, a discussion of the research surrounding the application of this functionality can provide insights into how it could be employed in the given context of supporting Engineering Design Communication.

In light of this, the following chapter introduces the concept of Social Media and discusses the common features of Social Media tools by reviewing of relevant literature from both Human Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW). Reflection upon how Social Media can be used to meet the previous requirements is made as well as eliciting a number of considerations when developing a Social Media approach. The relevant requirements will be indicated by R X.

5.1 A Social Media Perspective

From their beginnings in 1997, Social Media tools have fast become central to the digital lives of people in developed societies [Boyd and Ellison, 2007, Kaplan and Haenlein, 2010]. Figure 5.1 reveals the rapid development of tools over the past decade and it can be seen that the number of new tools is increasing rapidly year-on-year. To be considered a Social Media tool, Annanperä and Markkula [2010] simply requires them to be a '*technical solution that has been designed to help people to communicate*'. Boyd and Ellison [2007] highlights three key elements that a tool is required to meet in order to be considered a Social Media[1] tool. They need to allow the users to:

C1. construct a public or semi-public profile within a bounded system

C2. articulate a list of others with whom they share a connection

C3. view and traverse their list of connections and those made by others within the systems

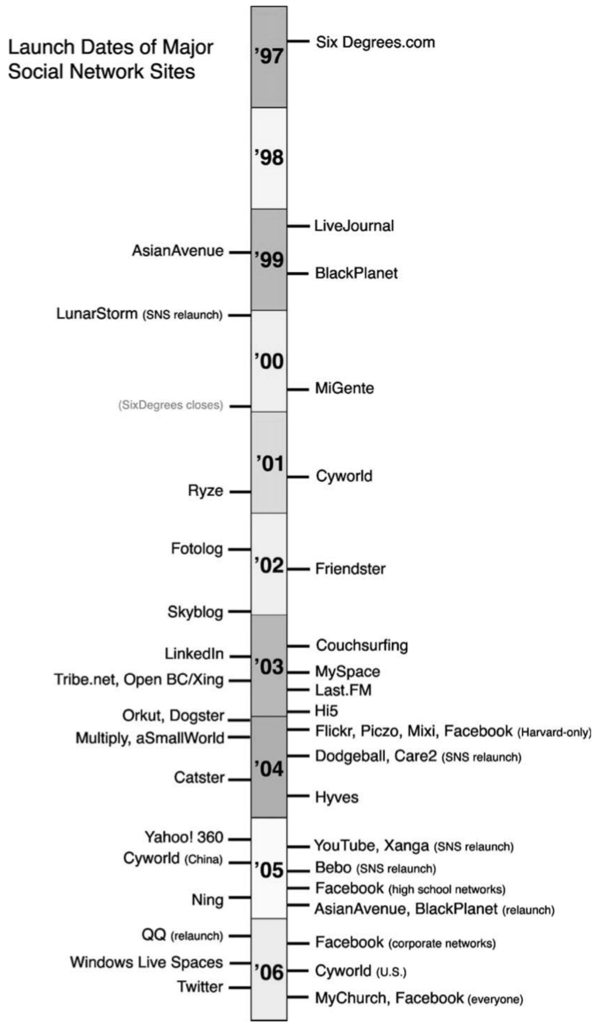


Figure 5.1: Launch Date of Social Network Sites (*From*: Boyd and Ellison [2007])

Considering this thesis' context, the requirements for supporting Engineering Design Communication has shown that some of the requirements do align with these elements of a Social Media tool. 1) Engineers need to be able to present their expertise, which would align with having a profile in the system. This could highlight which engineers should be contacted with regard to particular communications. 2) A number of potential connections to other colleagues have been elicited, which 3) could be as a method of traversing the communications within a potential tool (R 7, 8, 9 and 10). Boyd and Ellison [2007] continues their review by discussing the success such tools have had in niche communities and it is argued that an engineering company could be considered as such, due to Engineering Design Communication being highly-contextualised and have a specific relevance to only that project.

Guy et al. [2010] categorises the information sources within Social Media tools as either being people, things or places. In terms of supporting Engineering Design Communication this can be seen as the engineers, Engineering Records and where this communication lies within

[1]Social Network Site using their terminology

the Engineering Context. Begel and DeLine [2009] discusses that for a tool to be considered Social Media, users should have the ability to view and contribute to all/any of the content stored (albeit with privacy concerns taken into account). Thereby, enabling users to maintain awareness of the activities of others within the community. Therefore, this is an important aspect that needs to be considered when developing taking a Social Media Approach (C4). Figure 5.2 provides a visual similarity of Engineering Design Communication and the Social Media perspective discussed here. It is the ability to form the required connections between the content, communications and users within the given context that a tool can be considered Social Media. A tool is only likely to succeed if the users are able to form the relationships between communications and content they need [Breslin et al., 2007]. The relationships are important for users as they enable the search, retrieval and filtering of information, and therefore must be a consideration that the needs to be taken into account (C5). This further confirms the previous need to build the requirements for supporting Engineering Design Communication in the previous chapter.

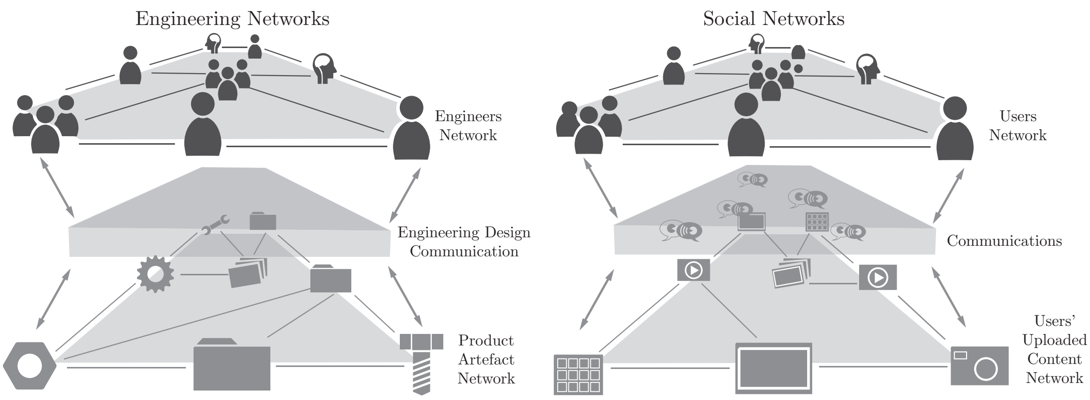


Figure 5.2: Similarity between Engineering Design Communication and the Social Media perspective

5.2 Application of the Social Media perspective

It is often the case that the application of Social Media has been performed through the use of web-based technologies, namely Web 2.0 and more recently Web 3.0 [Ellison et al., 2007, Boyd and Ellison, 2007]. Web 2.0 has been referred to as the people-centric web and has provided the features that have enabled the development of dynamic and interactive web pages [Murugesan, 2007]. Web 3.0 however, is known as the move towards the 'semantic web' where meaning can be placed on the relationships being formed between users, content and communications that computers can interpret [Morris, 2011, Hendler, 2008].

Using web-based technology has provided a suitable environment for Social Media development. It has enabled computing ubiquity, thereby enabling users to use whatever device they wish[2]. By being ubiquitous, it can be referred to as a lightweight tool as the computing requirements are not very demanding as well as also being able to perform any/all the function on any device a user wishes [Zhao and Rosson, 2009, Whittaker et al., 1997, Brzozowski,

[2]For example, a Personal Computer, laptop, tablet and/or mobile device

2009]. Törlind and Larsson [2002] expresses the need for any tool supporting Engineering Design Communication to be lightweight and thus, the use of web-based technologies appears to be a suitable solution.

In addition, being web-based enables the support of synchronous and asynchronous communication through the on-line storage of the information. This enables users to continue their discussions independent of schedules, time differences and location as long as an internet connection is available [Poile et al., 2009]. This is important as the research gap as identified in chapter 2 highlights the need for a distributed communication tool [Bellotti and Bly, 1996].

In order to form the relationships between users, communications and content, Social Media tools generally employ a form a collaborative tagging in addition to storing core meta-data such as author, date of creation and location [Ames and Naaman, 2007, Golder and Huberman, 2006]. As an example, FaceBook provides the users with the ability to tag other users within a photograph and has been incorporated in other photo software (see Figure 5.3). This enables the association between content and user to be formed. Bar-Ilan et al. [2008] highlights that best practice is to use both structured and unstructured tags. Structured being the tags that are required so that the information can be retrieved and unstructured being the optional tags that provide the opportunity for additional associations although they might not necessarily exist. Golder and Huberman [2006] shows how there is a typical explosion of terms to a given tag at the initial stages of a Social Media tool, which then begins to stabilise. They identify two types of users in such a system, users who use many of the terms and often generate new terms, and users that concentrate on using only a particular subset of terms. The tagging of the information is crucial to a Social Media tool as they are primarily used for learning, search & retrieval, and decision support [Sen et al., 2006, Smith, 2007]. Markines et al. [2009] highlights that keeping the tags extensible allows a potentially infinite number of terms, the tool can remain up to date with any changes to the terminology and/or information being added. One additional note is that there is potential to characterise the user by the use of these terms [John and Seligmann, 2006]. Therefore, three considerations need to made when applying tags; C6) to ensure core meta-data such as author, creation and location are captured, C7) to use structured tagging on meta-data that is a requirement for an information object within the system and C8) use unstructured tagging where potential meta-data could be applied but it is not a requirement for the item of information to exist within the system.

The communications within Social Media tool tend to retain their focus on the purpose of the communication and any '*off-topic*' communication becomes a separate instance in the tool [Hatem et al., 2012]. This is unlike Face-to-Face or E-Mail. This can be further improved with the use of character limitation within text-fields, which is also referred to as a psychological 'nudge' to ensure that only the key information is provided [Herring, 2001]. This inherent ability to maintain a communication instances focus would be potentially beneficial to Engineering Design Communication as well as the employing character limitation to potentially limit 'waffle' (R 14) [Perry and Sanderson, 1998]. Therefore, there should always be a consideration (C9) for the use of character limitation in order to maintain focus on a communication.

Notifications are also a commonly used feature within Social Media tools to ensure users are made aware of potentially interesting information. Such is the mainstream use of notifications, the new web standard HTML 5 is now incorporating the use of notifications as a core feature [Delgado, 2010]. These are '*typically lightweight, event-triggers that display information pe-*

images/removed-3.jpg

Figure 5.3: Tagging of users within photos in Facebook and iPhoto (*From:* All Things Digital)

ripheral to a person's current task-oriented concern, for example, system status updates, email alerts, stock tickers and chat messaging' [Carroll et al., 2003]. Brush et al. [2002] survey on the use of notifications revealed that it helped the users maintain awareness of topics of interest. It was also noted that striking the balance between sending enough notifications with the right content and yet, prevent notification overload is difficult to achieve and thus, cannot be solely relied upon as a means of ensuring collaboration within the system [Majchrzak and California, 2000]. To ensure that this does not become the case, users must be able to determine their notification preferences. Cadiz et al. [2000] further supports the benefits of notifications in enabling users to be informed of other user activity within the tool although additional work is required in their appropriate application and use. Therefore, one must consider (C10) the provision of a notification system within a Social Media tool for user activity and to ensure users are able determine their notification preferences.

Finally, Social Media tools make considerable use of commonly termed '*richer*' media such as photographs and videos [Kaplan and Haenlein, 2010, Mangold and Faulds, 2009]. This ability to upload images has drastically changed the way many people conduct their domestic photography [Lietsala and Sirkkunen, 2008]. Lerman and Jones [2006] analysis of Flickr - a photo sharing site - highlights that users readily browse the content created by others and are willing to comment upon it even though they do not know them personally. It is therefore suggested that this could be potentially useful given the Engineering Context. Additionally, Sit et al. [2005] & Sumi et al. [2008] assessments of their respective photo-sharing tools reveals how they see that photos can aid define the topic of communication (i.e. a picture of a broken item elicits a discussion of what happened). Therefore, one must consider (C11) how to take advantage of the fact that 'richer media' can aid browsing and the definition of the topic of communication.

5.3 Chapter Summary

This chapter has discussed the concept of Social Media and its associated application that has often employed web-based technologies. The reasoning behind how Social Media could be used to support Engineering Design Communication has been argued alongside the elicitation of eleven considerations in order to apply Social Media in a given a context. These have been summarised in Table 5.1.

Consideration No:	One must consider:
1	that users can present their expertise and differentiate themselves from one another.
2	that users can associate themselves with others.
3	that users can access all the content stored within the system (where possible).
4	that all the relationships between the users, content and communications are formed.
5	that users can access the Social Media tool independent of which device they choose to use.
6	that core meta-data such as author, creation and location are captured.
7	that structured tagging is used where there is a requirement for content to have such meta data.
8	that unstructured tagging is used to provide an opportunity for additional relationships to be formed.
9	that character limitation is used in situations where focus upon the communication needs to be maintained.
10	the provision of a notification system within a Social Media tool for user activity and to ensure users are able determine their notification preferences.
11	how to take advantage of the fact that 'richer media' can aid browsing and the definition of the topic of communication.

Table 5.1: Summary of the Considerations Elicited from SM Literature

Chapter 6

A Social Media Approach to Support Engineering Design Communication

Taking the previous chapters' consideration in applying Social Media and requirements for supporting Engineering Design Communication, this thesis continues the Prescriptive I element of the DRM framework by proposing a Social Media approach that should be pursued when developing a Social Media tool to support Engineering Design Communication. This proposition has been based upon the alignment of the requirements and considerations, which has led to the development of the features that would be necessary for the supporting Engineering Design Communication using Social Media. These present the features that a user of the Social Media tool would find themselves using. The following chapter provides an overview of the features proposed and provides the reasoning behind each feature. In summary the Social Media approach consists of:

1. A Communication Process (Figure 6.1), which demonstrates how the communication is created and evolves within an Social Media tool.
2. A EDC classification matrix (Table 6.1) developed by combining the previous tables developed during the requirements stage. This presents how the communications between the engineers within a Social Media tool should be semi-structured by the purpose of the communication, the types of response that should be permitted and the potential resulting outputs from the communications.
3. The approach consists for five stages. Each are discussed in their respective sections in this chapter, where the functionality and the data & information requirements that have to be met for that stage of the process is described

This chapter provides a description of each stage of the communication process and the SM tool requirements in terms of functionality and the data and information to be captured. Reference to the requirements listed in Table 4.9 as well as considerations in Table 5.1 are made throughout. These are presented as R and C respectively. In addition, each section presents how a Social Media tool (known as PartBook) meets these requirements.

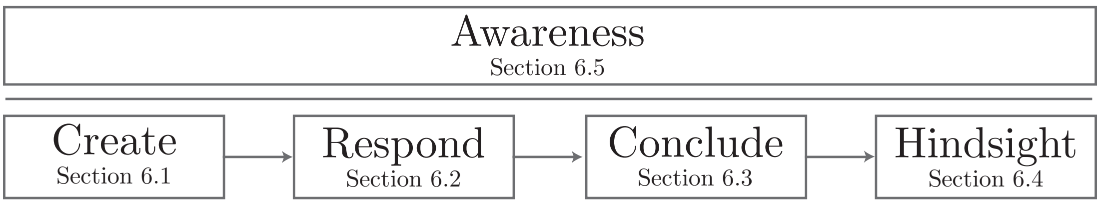


Figure 6.1: The Communication Process of the SM Framework to Support EDC

	Communication Tag Types (Purpose of the Communication)									
Type	Idea	Help	Issue	Clarification	Confirmation	Comparison	Option Generation	Information Request	Observation	Decision
Description	Wants to Show Something Potentially New	Wants to Solve a Process Problem	Wants to Solve a Product Problem	Wants to double-check their knowledge on a subject	Wants to ensure the artefact is correct	Wants to Converge on a Solution	Wants to Generate a number of solutions to a problem	Wants to receive or the location of information with regards to a particular subject	Wants to highlight an Artefact of Potential Interest	Wants to propose a decision and wants engineers input
Example	I have an idea about a new Bike fork which would save us weight on the front end. What do you think?	How do I go about performing an FEA analysis on Bike fork?	I have another torn tyre on this bike model. Is there anything to prevent it keep happening?	Does the number of cells near the body boundary have a significant effect on the CFD solution?	I have just performed a suspensions analysis on this bike and was wondering if these answers look right?	I have three different fork design anyone have any ideas on which one to go for? We are designing a mountain bike.	Does anyone know how we could provide rear suspension to he back of the bike?	Does anyone know where I could find some material properties and prices for steel suppliers we deal with?	I saw this bike which has single spoke wheel and the frame bends out so that it enables them to fit the gearing within the centre of the bike wheel.	Right, I am proposing that we go ahead with manufacturing this bike from steel.
Response Type Tags										
Opinion: wants to give their own personal view across	I like it. I think you might have something there	The Process Manual is not great so I would talk to someone who has recently done it.	It could be the pressure youre putting into the tyre, which is making it dig into the rim too much.	I know that it effects the result from a turbulent CFD calculation much greater than if you considering just laminar.	I think it looks right	This design would probably have to be outsourced and thus would cost a pretty penny.	I think we need to consider manufacturing capability with some of these options.	I think the website will be a good source for initial scoping and only bother someone if you have got the go ahead with the project.	That's one cool looking bike. I am not sure if it provides much apart from decreasing the rear width of the bike.	
Experience: wants to express a view based on their own experience	We tried something similar 5 years ago with the XX project	When I did it I followed this process guide XXX.	I have seen this before with the these rims. We had to file the rim edge as they were digging into the tyre wall.	I have always used cell layer of around 10 for the CFD calculations I have performed and it has generated good results	They look very similar to the numbers we usually get when designing a comfort bike	Whenever we have done a mountain bike design we have used XX because of this	I was on the team that did a feasibility study on the rear suspension	I have talked to XX in the past and he was always good at providing me with a quick response	Although, it may make the bike look different . Our market analysis has shown that there is nota gap to support the manufacture of one.	
Observation: wants to show an artefact of potential interest	I saw this working, which shows it could work	This is the results I have seen from past fork FEA.	We have been having the same problem too. So nothing unique.	I have seen people use between 5 and 15.		I have seen this mountain bike which is doing well at the moment and they have gone for this design	I have seen some concepts using a gel bubble within the arm which looks interesting			
Guidance: wants to express something that the engineer should consider	If you wish to progress with this idea then you should talk to Joe Bloggs within R&D	I think you should consult the FEA section on the wiki and there should be a section	You could get into contact with the design team and see if they can modify the rim for subsequent bikes being manufactured having the same problem.	A high resolution is required for high speed turbulent flows so that the calculations can resolve the boundary layer. You should consult section X which has greater detail on the subject.					I have seen this concept which directly drives from the wheel rim.	
Action: wants to inform the engineer on what he/she has to do	Even if you do not take this further, you must report it within the XX Database so that there is a full record of the proposal	Check out this section on the website and talk to Joe Bloggs as he has recently performed one.	Could you ensure that you fill in a service report with what you have done to rectify the problem.	Read this guide and it will provide you with enough detail on the mesh details you would require for your test					There is an R&D team looking at designing a luxury high end bike so I would pass this on to them.	
Idea: wants to introduce something potentially new to the conversation	If we coupled this design with the ZX Bike frame then we could be onto a winner		If you did not want to file the rims then you could possible glue a piece of rubber to the rim to act as a cushion				Maybe we could try layering materials like they did in the samurai sword to provide some suspension within the arm		How about two wheel drive?	
Affirmative: wants to acknowledge a statement that has been made	I hear you, I will process this through the XX database	Sure thing, I will get in contact with him	Alright, gotcha. I will get onto it.	Alright I will read that.					Ok I will look into the past design stores.	
Location: want to provide the location of some potentially useful information	I hear you, I will process this through the XX database	Sure thing, I will get in contact with him	Alright, gotcha. I will get onto it.	Alright I will read that.				This is the suppliers site and our log in is this XX so we can generate an initial quote		
Agree: wants to express a positive stance on an engineers viewpoint					I have looked at the results and they look good					Yes I agree with the proposed decision
Disagree: wants to express a negative stance on an engineers' viewpoint					I think you may have forgotten to change the stiffness of the front fork					I do not agree because it will be far too heavy compared to its competitors.
Warning: wants to highlight areas to be wary of		Make sure youre using the most recent process manual. There have been some changes to the CAD files we now use.	Filing the rim will invalidate the warranty of the rims so may want to consider another solution.	If you unsure about mesh creation. Talk to XX as it can be a minefield to which values you should and should not change.						
Valid: wants to highlight a valid point that has been made without positioning themselves					Joe has a valid point on your material selection but that change shouldn't impact too much.					Most competitors are indeed using aluminium or carbon fibre these days
Not-Valid: wants to highlight and give reason for an invalid point made by a colleague and to not position themselves					This would be right if you considering manufacturing using this method (XX) but you could try this					Some riders still prefer a steel bike for the endurance runs as it can.
	Conclusion Tag Types									
	Good Idea: Pursued Good Idea: Did Not Pursue Not Plausible Already Conceived	Resolved: Process Lesson Learned Unresolved: Possible Process Issue	Resolved: Product Lesson Learned Unresolved: Possible Product Issue	Clarified Not Clarified	Yes: All Good No: Amendments Required No Confirmation	Option Selected No Option Selected Hybrid Option	Options Generated Lack of Options	Received Useful Information No Useful Information Received Lack of Information	Item of Interest Non-Consequential Good Work Seen Before Possible Issue	Decision Made No Decision Made

Table 6.1: The Communication Classification Matrix of the SM Framework to Support EDC

6.1 CREATE

The CREATE stage of the SM communication process handles the creation of the communications within the SM tool (termed 'communication objects'). Table 6.2 presents the features that must be employed by a SM tool wishing to support EDC.

SM Feature No.	Status	SM Feature	Description	From Requirements
1	Required	Character Limited Textual Input of Engineers Statement	The statement that the engineer wishes to make to start the communication	R:14, C:9
2	Required	High Quality Image of Artefact	A photograph or screenshot of the artefact of interest that supports the purpose of the communication	R:1, C:2
3	Required	Artefact Type Tag	A tag to identify the type of artefact that is being captured such as CAD, CFD, Sketch, Model, the Product, for example	R:4 C:7
4	Required	Artefact Focus Tag	A tag to identify the 'focus' upon the artefact that has been captured such as an error message, tolerancing, mating for CAD for example	R:5 C:7
5	Optional	URL/Identify the Location of the Artefact through a Textual Input	This tag provides the opportunity to provide the location of the artefact pertaining to the purpose of the communication.	R:6, C:8
6	Required	Communication Type Tag	The engineer is required to provide the tag that describes the purpose of the communication such as presenting an idea, asking for help or highlighting an issue for example. (see communication classification)	R:11, C:7
7	Optional	Product/Part Tag	These are optional tags that should be used where the communication aligns to either a product and/or part	R:20, C:8
8	Optional	Project/Activity Tag	These are optional tags that should be used where the communication aligns to either a project and/or activity	R:20, C:8
9	Optional	Concept/Feature Tag	These are optional tags that should be used where the communication aligns to either a concept and/or feature	R:20, C:8
10	Optional	Product Lifecycle Stage Tag	This are optional tags that should be used where the communication aligns to the Product Lifecycle	R:20, C:8

Table 6.2: Information Features during the CREATE stage

The engineer(s) creating the communication object are required to upload one high-quality image of the artefact pertaining to the communication alongside their statement, which is to be captured through a character limited free-form input. There are also contextual requirements to be considered and the engineers are required to tag the communication with the purpose of the communication, artefact type and artefact focus, as well as providing optional tags to capture the links to the actual artefact, align to Company, Product and phase of the Product Lifecycle dimensions, which are to be applied where applicable at the engineers discretion. Finally, there is the provision for additional information that should be associated with the communication.

Upon completing the CREATE stage, the communication object becomes instantiated within the SM tool and engineers are able to contribute to the object. The communication object now moves to the RESPOND stage.

6.2 RESPOND

The RESPOND stage handles what can be considered the 'live communication' element of the process, whereby the engineers are able to contribute and discuss the communication object. Table 6.3 presents the features that are to be employed by the SM tool during this stage.

SM Feature No.	Status	SM Feature	Description	From Requirements
11	Required	Character Limited Textual Input of Engineers Statement	The response statement that the engineer wishes to make	R14, C:9
12	Required	Response Type	The engineer is required to provide the tag that describes the type of response that they are making such as providing an opinion, talking from experience or providing guidance for example. (see communication classification matrix)	R:13, C:8
13	Required	One or More Links to Statements within the Communication	The engineer is required to indicate which statement/s within the communication object that they are referring to.	R:15, R:16, C:4
14	Optional	High-Quality Image of Supporting Artefact	This provides the opportunity for an engineer to add supporting evidence to their response through the upload of an image.	R:3, C:11
15	Optional	URL/Identify the Location of Artefact through a Textual Input	This tag provides the opportunity to provide the location of the artefact pertaining to the purpose of the communication.	R:6, C:8

Table 6.3: Information Features during the RESPOND stage

Engineers contributing to the communication object are required to make their statement through a character limited textual input alongside the need for them to tag the statement with the response type determined by themselves from the Engineering Design Communication classification matrix (Tables 6.1). Only the response types indicated for that purpose should be present within the communication object. However, it has previously been mentioned that this is not an exhaustive list and that engineers should have the option to add additional terms if required. The engineer/s are also required to highlight the previous statement/s that they are referring to and the RESPOND stages should handle the multi-threaded aspect of the communication object. Providing this reference will enable engineers to be able to trace the evolution of the communication within the object. The engineers should be provided with the ability to provide a representation of a supporting artefact and as before, this is to be performed through the capture of a high-quality image. They should also be provided with the ability to link the artefact to its 'real-life' counterpart through either a Universal Resource Locator (URL of an electronic file) or stating the physical location. This stage continues until the originating engineer/s deem that they are able to conclude the communication.

6.3 CONCLUDE

The CONCLUDE stage of the process arises when the originating engineer/s deem that they have reached a suitable conclusion to the original statement made at the CREATE stage. Table 6.4 presents the SM features during the CONCLUDE stage.

SM Feature No.	Status	SM Feature	Description	From Requirements
16	Required	Character Limited Textual Input of Engineers Conclusion	The originating engineer/s create the statement that concludes the communication and highlights the outcome of the communication.	R:14, C:9
17	Required	Conclusion Type	The engineer is required to provide the tag that describes the type of conclusion that has been achieved from the communication such as, clarified or not clarified in the case of a clarification communication (see communication classification matrix)	R:17 C:7
18	Required	One or More Links to Statements within the Communication	The engineer is required to indicate which statement/s within the communication object that they are referring to.	R:15, 16 C:4
19	Optional	High-Quality Image of Concluding Artefact	This provides the opportunity for an engineer to add supporting evidence to their response through the upload of an image.	R:3, C:11
20	Optional	URL/Identify the Location of the Artefact through a Textual Input	This tag provides the opportunity to provide the location of the artefact pertaining to the purpose of the communication.	R:6, C:8

Table 6.4: Information Features during the CONCLUDE stage

The originating engineer(s) concluding the communication are required to define the type of conclusion that has been reached and make their concluding statement through a character limited free form textual input. There should be the option for the engineer(s) to capture a final artefact, again, through a high-quality image and to link it to the 'real-world' artefact where possible. This can be considered as an opportunity to highlight the impact the communication has had on the artefact. Again, this has to be linked to either one or more statements, created during the CREATE/RESPOND stages, within the communication object.

The communication is no longer in the 'live communication' phase and is now stored for re-use.

6.4 HINDSIGHT

The HINDSIGHT stage of the SM communication process to support EDC handles the direct re-use of the communication objects that are now stored within the tool. Table 6.5 presents the SM features to support the HINDSIGHT stage.

SM Feature No.	Status	SM Feature	Description	From Requirements
21	Required	Character Limited Textual Input of Engineers Hindsight Statement	An engineer creates a statement that refers to the past communication object and discusses why the reference has been made	R:14, C:9
22	Required	Referral Type	The engineer is required to indicate the type of referral they are making to communication object	R:19 C:8
23	Required	One or More Links to Statements within the Communication	The engineer is required to indicate which statement/s within the communication object that they are referring to.	R:16, C:4

Table 6.5: SM Features during the HINDSIGHT stage

Engineers are able to search and retrieve past communication objects and they are able to refer back to past communication objects and highlight how they have been re-used. They are required to specify the type of referral they are making to the communication object by adding their statement within a character limited free-form textual input and provide one or more links to existing responses within the communication object.

The communication object now lies within the state continually within the SM tool.

6.5 AWARENESS

AWARENESS features should be present throughout the whole SM communication process and are summarised in Table 6.6. They are features that assist in ensuring that the right engineers are made aware of relevant communications to which they are most able to contribute.

SM Feature No.	Status	SM Feature	Description	From Requirements
24	Optional	Reference to Engineers	This is present to enable engineers to refer communications to one another and aid the visibility of the communication to the most suitable engineers.	R:7, C:4, C:8
25	Optional	Reference to Past Communication Objects	This is present to enable engineers to support their statement by making reference to past communications and to see how communication lead to the generation of new communication and in effect achieves traceability through the communication network.	R:18, C:4, C:8
26	Optional	Reference to Task Groups	This is present to enable engineers to make communications visible within their task groups and in effect enabling the grouping of communications by task.	R:8 C:4, C:8
27	Optional	Reference to Expert Groups	This is present to enable engineers to refer communications to experts groups (core competencies) within the company and ensure that the communication is made visible to the most suitable set of engineers.	R:9, C:4, C:8
28	Optional	Reference to Personal Bookmark	This enables engineers the make reference to communication for their own bookmarking purposes for potential later re-use.	C:4, C:8
29	Required	Search, Filtering and Retrieval using the Captured Context	Engineers are able to search, filter and retrieve communications using the captured meta-data throughout the communication process	R:5, C:1

Table 6.6: SM Features during the AWARENESS stage

Engineers should be able to refer communication objects to other engineers. This allows the tool to take advantage of the engineers social knowledge to ensure the communication objects are made visible to the right engineers. To ensure traceability of communication objects and their consequences, there should be an option to refer back to past communications. This enable engineers to support their statements within current communication objects and to also highlight communication objects resulting from previous communications. In addition, there should be the capability to refer to task and expert groups to ensure that the right set of engineers are made aware of the communication objects and to make reference to personal bookmarks to enable engineers to have quick reference to key communication objects. Finally, there is a requirement for the tool to provide the functionality for the engineers to be able to search, filter and retrieve based upon the contextual meta-data that has been captured throughout the communication process. This is to ensure that engineers are able to be made aware of communications of potential ‘interest’ to them.

6.6 Chapter Summary

This chapter has presented the proposed Social Media approach by this thesis that has been built upon the requirements for supporting Engineering Design Communication and the consideration that have to made in order to apply Social Media. The approach consists of a Communication Process, Engineering Design Classification matrix and description of the features at each stage of the process where specific data and information requirements have to be met. A total number of 29 Social Media features have been defined.

Chapter 7

The Development of a Social Media Tool - PartBook

To evaluate and validate the previous Descriptive I and Prescriptive I work and move towards the Descriptive II stage of the DRM framework, this thesis now discusses the instantiation of the Social Media approach within a tool called PartBook. PartBook uses PHP, MySQL, HTML5, Javascript & CSS3 as the underlying web-based technologies and has been solely developed by the author. The use of web-based technologies ensured that it could be made accessible on any computer enabled device the users wished to use (C5).

This chapter beings by discussing how the tool has been iteratively developed through internal review and testing by an University Group Business Design Project. This is followed by a section describing the version of PartBook that is to be tested within industry and the main Formula Student study. The industrial study's main objective is to provide a means to test the usability of the developed tool prior to the main study. In addition, it provided an opportunity to provide a survey into industry that has provided a current view of communication practices of industry. This has been used to reflect upon any potential changes in communication behaviour from what has been previously observed in the literature. Figure 7.1 further highlights the stage that this thesis has reached with respect to the research timeline.

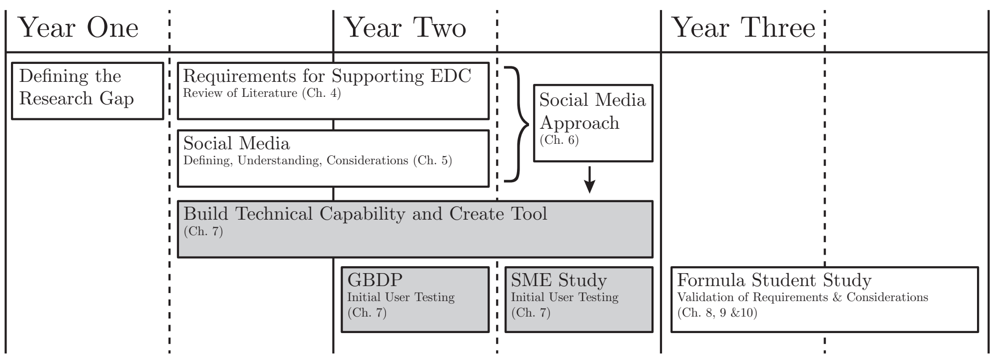
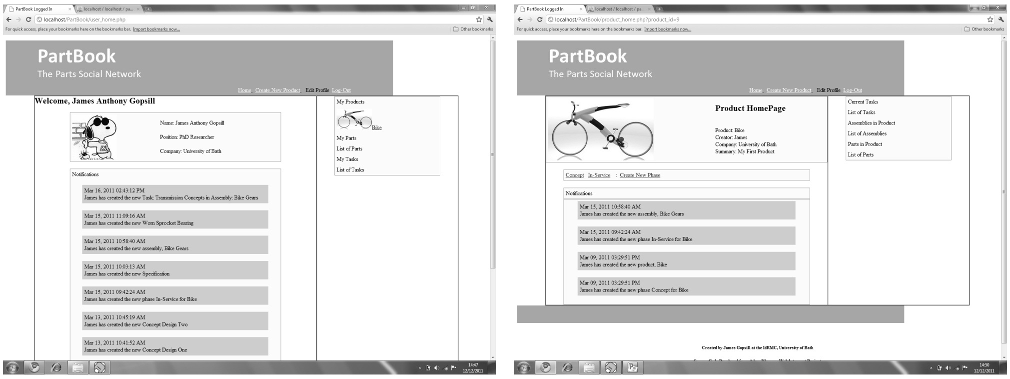


Figure 7.1: Stage in Research Timeline



(a) User Home Screen (b) Single Thread Discussions

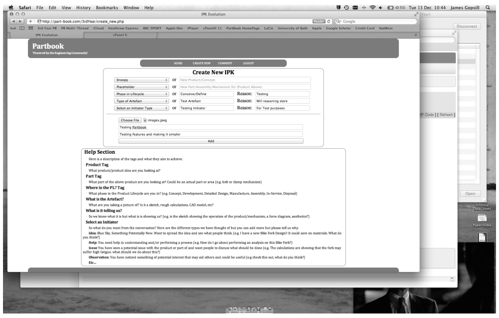
Figure 7.2: Initial Development of PartBook

7.1 Iterative Development of PartBook

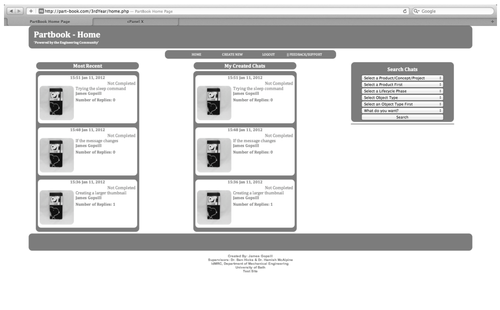
Due to the time-scale of the PhD, the development of PartBook coincided with the review and development of the requirements to support Engineering Design Communication. It has been developed iteratively over the three year period involving feedback from both internal sources as well as industry. This section provides some more details on the development of the tool in order to satisfy the need of the flexible research strategy to ensure the reader understands the tool that is to be used within the study.

Figure 7.2 shows the initial steps taken to develop the web-based tool. The primary focus was the development of ones skill set in using these technologies and initially the tool had the appearance of many other social networking websites. 7.2a shows a home profile of a user with the ability to send notifications and provides updates to that user. 7.2b shows the capability of capturing and performing single threaded communications.

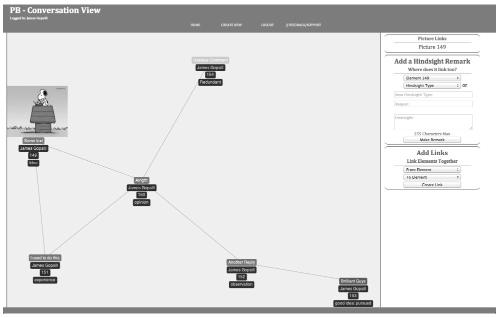
As the capabilities and proficiency of using the technologies continued, a tool that met the Social Media Approach was developed. Figure 7.3 shows the first steps towards a tool that provides the functionality that meets the Social Media features required. 7.3a shows the functionality required for the CREATE stage and where an engineer would create a communication within the tool. 7.3b shows the home screen for a user which provides the functionality required to show communications that the engineer may be of interest to. 7.3c was the initial attempt at multi-threaded communications using nodes positioned using a force-based algorithm. However, the communication never settled fully thus making it hard to read the communication. Finally, 7.3d shows the development of the underlying database structure that was used to store and capture communications and activity within the tool (Full Database Schema is in Appendix B.1).



(a) Create Communication



(b) Home Screen



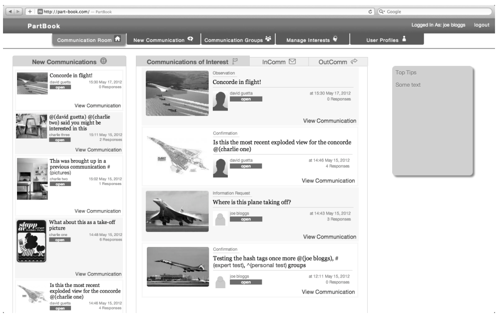
(c) Multi-threaded Discussions

(d) Database Table Structure

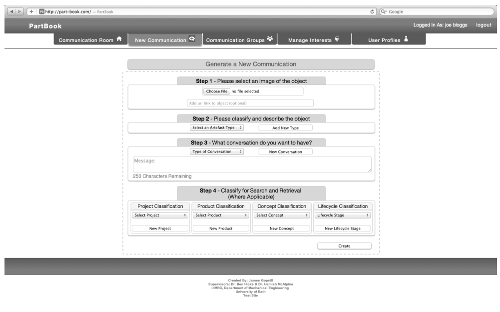
Figure 7.3: Iteration of PartBook

7.2 PartBook

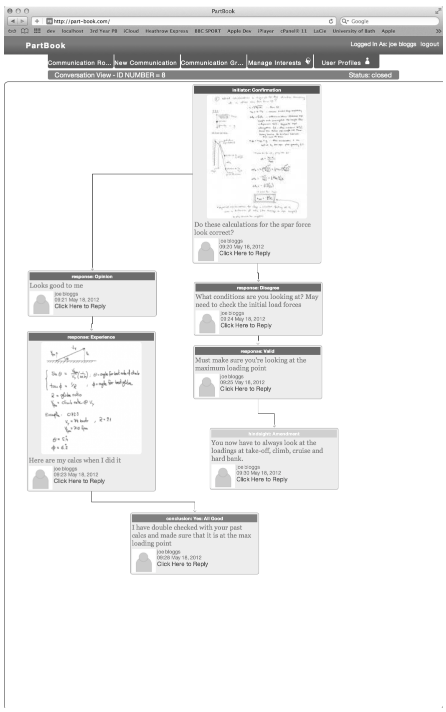
The development of the tool continued until it reached the version that is discussed here (Figure 7.4). This tool continued its development through industrial feedback (discussed in the next section) and finally tested within the Formula Student study (discussed in the next chapter). This section discusses how the tools functionality meets the Social Media features required by the Social Media Approach (referred to in the text by SM:X) as well as the considerations to taking a Social Media approach (C:X). Re-iteration of the reasoning for this functionality is also provided in order to understand 'why' this would be needed by an engineer wishing to communicate to others.



(a) Home Screen



(b) Create a Communication



(c) A Communication in PartBook

(d) Desktop and Mobile

Figure 7.4: PartBook Screenshots

7.2.1 Creating a Communication

The creation of a communication within PartBook has four steps that need to be completed (Figure 7.5). Step one of creating a communication requires the engineer to upload an image of the artefact to which the communication is pertaining (SM:2), with an additional feature enabling the engineer to provide the URL/real-world location of the artefact (SM:5). To reiterate the previous chapters, the role of the image is to provide a 'temporal snapshot' of the artefact at the time the engineer wishes to initiate the communication. This enables participating engineers to further understand the engineering context surrounding the communication. The URL/real-world location enables quick access to the artefact.

Moving to step two, the engineer is required to tag the communication with respect to the type of artefact (for example, a CAD file) that has been selected alongside the '*focal point*' on that artefact (for example, Error Message) (SM:3,4). Again, this is building the engineering context that surrounds the communication and also enables the aggregation and filtering of communications based on these dimensions.

Step three is where the engineer types their message. There is a 250-character limit to maintain conciseness and thereby prevent '*waffle*' [Perry and Sanderson, 1998]. The appropriate size of an engineering message is still to be tested but has set at 250-character as it is argued that engineering terminology typically contains more characters yet the principle is to have a similar formulation of the message seen in the 160-character limited SMS and Twitter messages (SM:1). The engineer is required to select the type of communication they wish to have (for example, idea, clarification or decision) (SM:6). This plays an important role as it depicts the type of responses that participating engineers can make and focuses the communication towards a limited number of possible outcomes.

Finally, step four provides the opportunity for the engineer to align the communication against the project, activity, product, part, concept, feature and lifecycle stage (SM:7,8,9,10). The main role of these tags is for search, retrieval and to be used by the **AWARENESS** part of the communication process, which is discussed later. Once completed, the engineer can click 'Create' and this generates the communication within PartBook whereby engineers are able to respond to it.

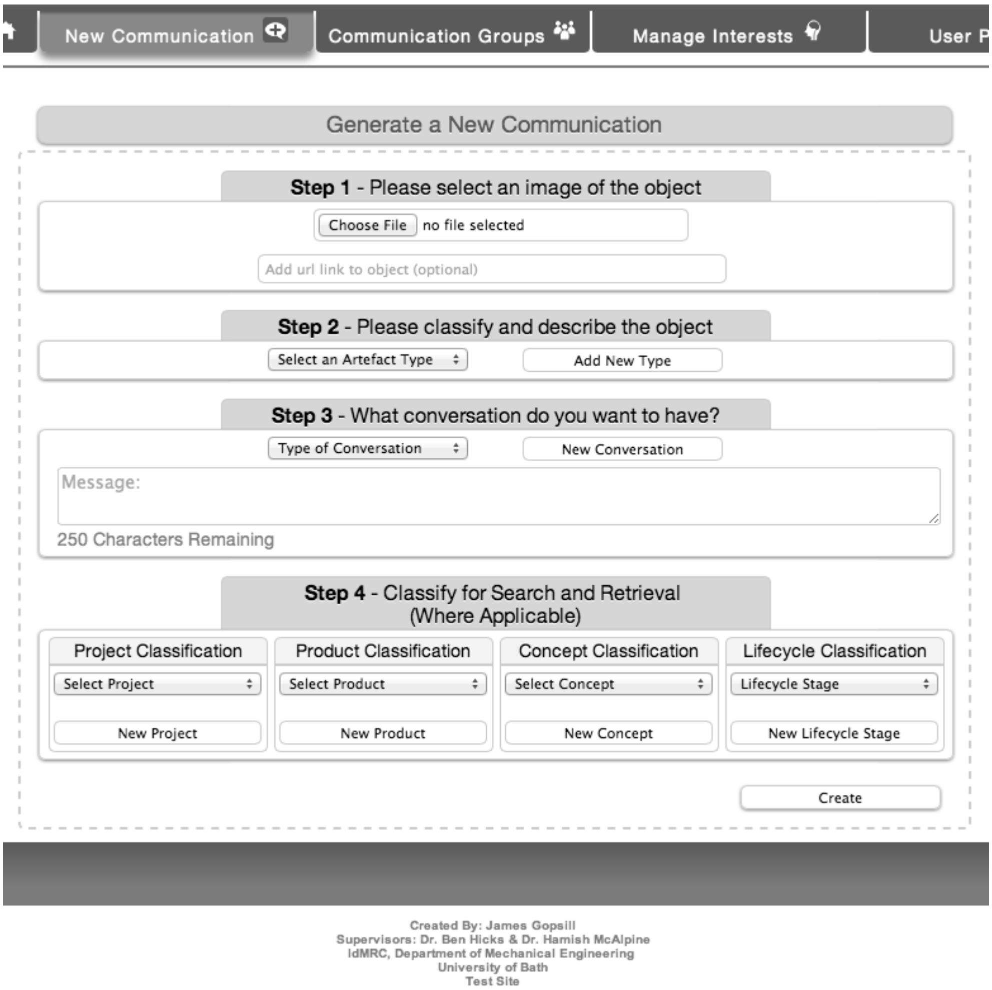


Figure 7.5: Creating a Communication within PartBook

7.2.2 Replying to a Communication

Once created, the engineers are able to access and respond to the communication from the within tool. Figure 7.6 demonstrates the multi-threaded functionality of the PartBook tool and this enables engineers to present various perspectives concurrently as well as enabling the divergence and convergence of ideas/discussions (SM:13). Engineers can select one or more elements against which their response will be associated and manually position their response. Again, the response is character limited and the engineer is required to select the type of response that they are making (SM:11,12). The type of response uses a drop down menu containing types of response expected based on the Engineering Design Classification matrix. Although, an engineer is able to generate a new type of response as it has already been contended that it may not be a exhaustive list of types. The aim of which is to enable other participating engineers to understand '*where they are coming from*'. The engineers are also able to add supplementary artefacts through the upload 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) (SM:14). The images are immediately viewable with the text in order to maintain the focus of the communication on its initial purpose (C:11). The engineer can also place a URL link or location of a file within their response (SM:15). The communication remains within this stage until the originating engineer determines that it has reached its conclusion.

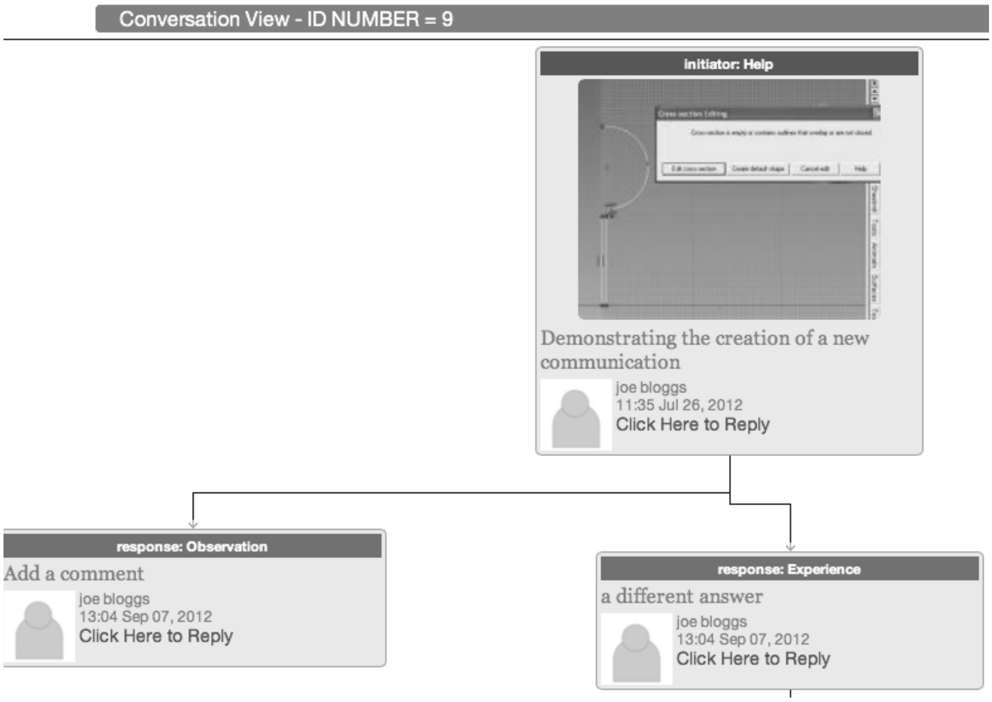


Figure 7.6: Responding to a Communication within PartBook

7.2.3 Conclusion of a Communication

The originating engineer determines whether the communication has reached its conclusion (Figure 7.7). The engineer is required to select the type of conclusion that has been reached (for example, problem solved) as well as providing a final comment detailing the result of the communication, which is again character limited (SM:16,17). They are also able to provide a final image of the artefact with its location, which could be used to record the consequence(s) of the communication on the artefact (e.g. the modified CAD drawing) (SM:19,20). The engineer has to link the conclusion element to either one or more of the previous communication elements to show where the conclusion has come from (SM:18). By concluding the communication, the engineer effectively moves it from the current use state to an archived re-use state. This leads to the **Hindsight** stage.

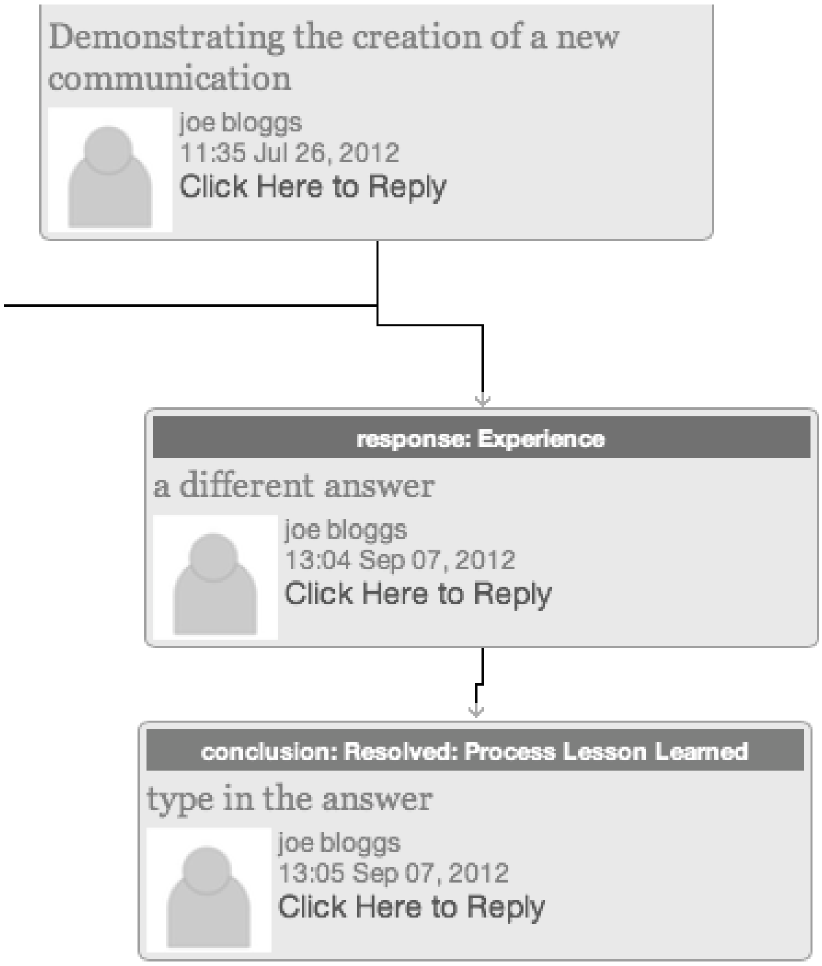


Figure 7.7: Concluding a Communication within PartBook

7.2.4 Hindsight of a Communication

The communication is now in an archive re-use state and **Hindsight** enables engineers to place comments and refer back to these past communications. Examples could be to highlight redundancy, best practice and/or make amendments (Figure 7.8). As with the previous stages, the engineer is required to direct these comments to particular elements of the communication, highlight the type of hindsight being made, as well as making their comment, which is character limited (SM:21,22,23).

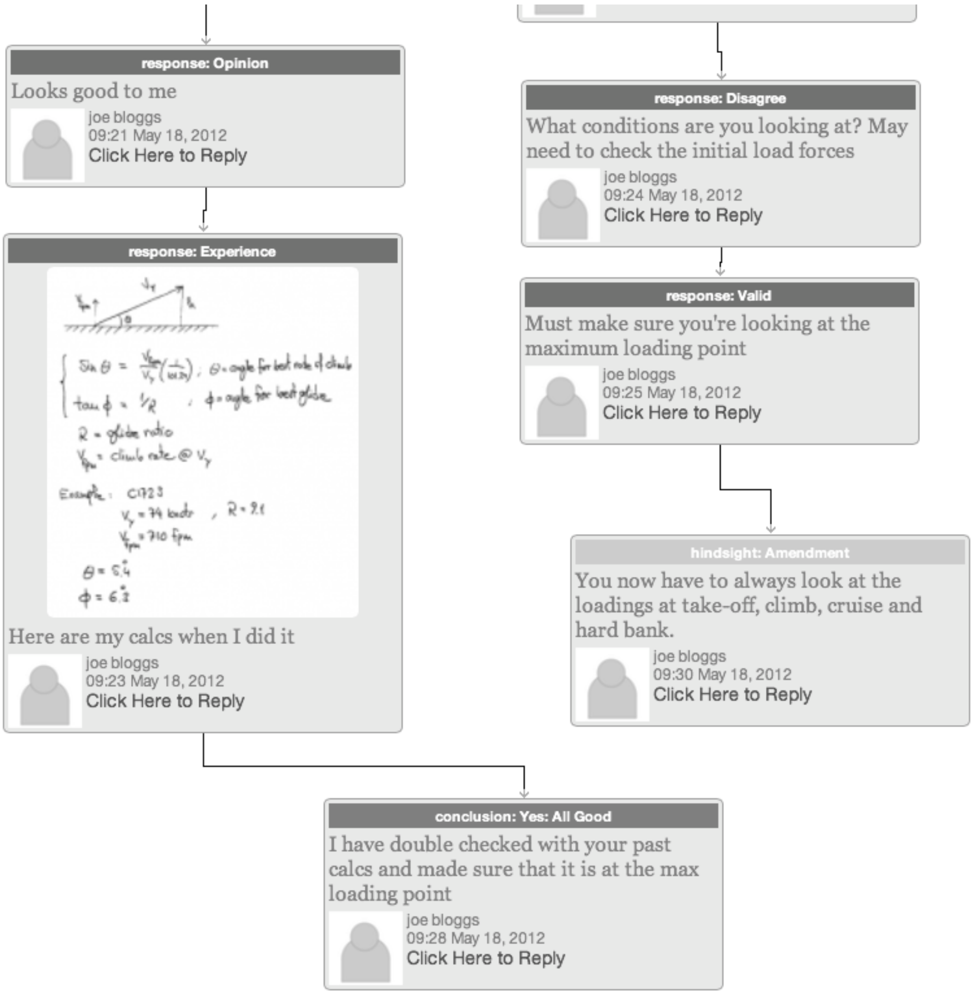


Figure 7.8: Referring back to a Communication within PartBook

7.2.5 Awareness of Communications

Throughout the communication process, PartBook provides functionality that is aimed at ensuring the *right* engineers are made aware of communications to which they could potentially contribute. This functionality comes in the form of tags that can be applied within any textual element (referred to as #tags). The engineers are able to notify one another through the use of @(Joe Bloggs) for example, thereby supporting the use of the engineers' social knowledge to send the communications to *right* engineers (SM:24). There are also a number of #tags that enable the grouping of communication for personal bookmarking, task and expert groups (SM:26,27,28). Engineers have the opportunity to #tag other communications allow the sharing of rationale and enable traceability of communications that influence other communications (SM:25). The final aspect is the ability to take advantage of all the tags being used within the system so that engineers are able to generate so called '*interests*'. An *interest* is a selection of tags chosen by the engineers and this enables the customisation of the communication feed they see (Figure 7.9, SM:29). The aim is to present the *right* communications to the *right* engineers.

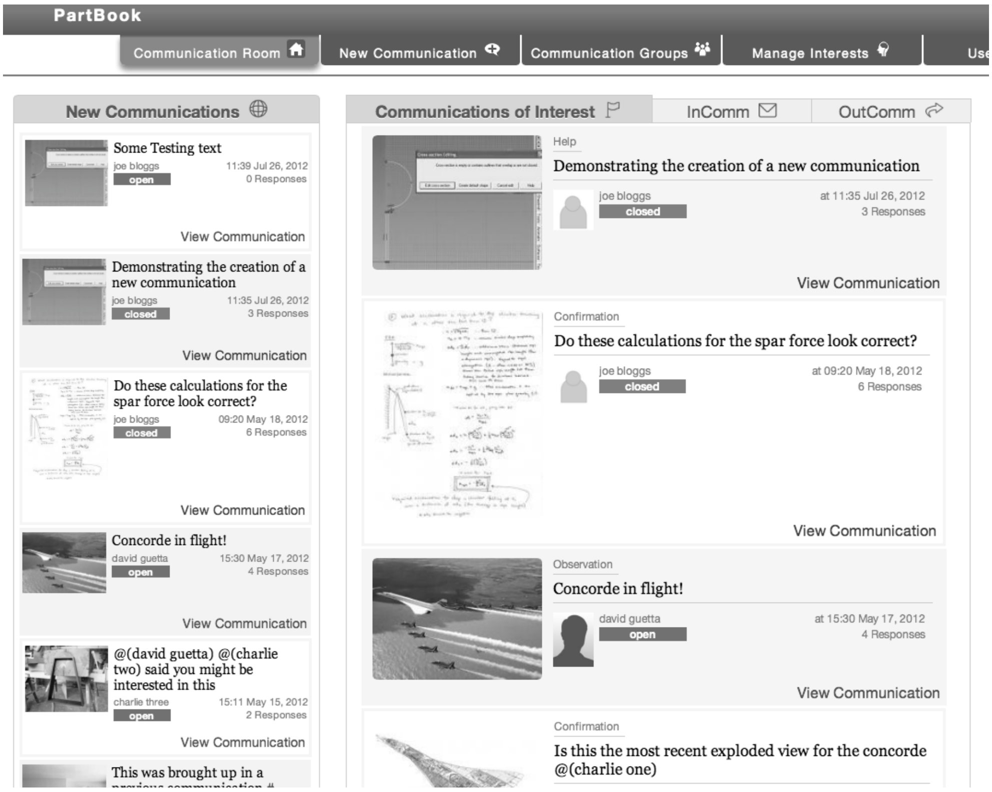


Figure 7.9: Referring back to a Communication within PartBook

To further ensure that the engineers are made aware and maintained awareness of communications within the PartBook tool, a notification system has been developed. Figure 7.10 demonstrates the notification that an engineer would receive by the tool. Currently, it comes in the form of an e-mail as the development of a 'push' notification system would have taken too long. The system notifies engineers on new communications within the tool and can be tailored based upon the tags that - as previously stated - the engineer is 'interested' in.

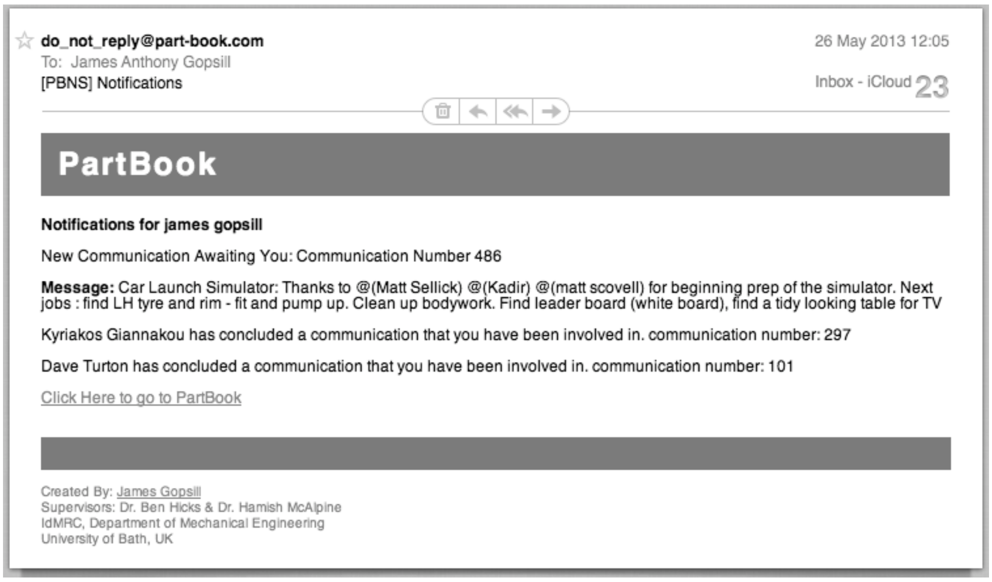


Figure 7.10: PartBooks Notification System

7.2.6 PartBook Summary

The previous sections have presented how a user would proceed through the communication process within the PartBook tool. In summary, their are a total of eight key web pages that form the PartBook website and these are described in Table 7.1. In total, the website consists of 139 page templates, styling sheets and server-side scripts. The MySQL database contains fifteen tables in order for PartBook to operate. Example code and an overview of the database is provided in Appendix B.1.

Web Page	**Description**
Index Page	The first page you arrive at when accessing the PartBook website. The users log in and also register here.
Registration Page	A user can register themselves here
Home Page	This provides the users with the home page that serves up the recent communications, the communications the user has been involved and provides potentially *interesting* communications to the user (Figure 7.9).
Create Communication Page	This is where a user can create a new communication within PartBook (Figure 7.5).
Communication Page	This is where a user can contribute to a communication, be it through a response, conclusion or hindsight (Figure 7.4c).
Group Page	This page displays the various groups generated by the users through the use of the Expert, Task and Personal Bookmark Tags.
Interests Page	The users are able to assign their interests by selecting the tags that they wish to receive notifications on.
Profile Page	Displays the users profile information as well as enabling them to edit their profile information.
Help Page	Provides help information on the functionality within PartBook

Table 7.1: A summary of the web pages that make up PartBook

7.3 Industrial Study

In order to ensure the prototype is suitable for implementation within an engineering project, the tool was tested by engineers within a local Small-to-Medium Enterprise (SME) in Bath, United Kingdom. This was performed as a 30 minute aside from their engineering work to assess the performance of the tool and to highlight any issues over the course of a four week period. It also provided a chance for a study to understand this companies' current communication practices as well as providing an insight into the purposes of their communications that could be compared to the extant review of Engineering Design Communication. The testing of the tool alongside the study into their communication practices is now discussed.

7.3.1 The Study Context

The company provides health care and assistive products to aid people with disabilities in their daily living. These range from products with few components, fully electronic-based products to fully motorised products. Their employment ranges from 20-40 people (dependent upon workload and contractual agreements) of which approximately two thirds have an engineering background. It can be seen from their broad range in product portfolio, that the engineers are involved in multiple disciplines and constantly changing product complexity (See for example, Figure 7.11). The company is based within a single building consisting of two floors with engineering workshops and test space on the 1st and offices on the 2nd.

An introductory meeting was held and the tool presented to the engineers of the company alongside a demonstration of the tools functionality. The engineers were informed to spend at least 30 minutes during the week generating and replying to communications using the tool. A feedback session where minutes were taken was performed at the end of every week during the trial. The trial lasted a period of four weeks.

As with previous studies within the field of engineering communication research, a survey was used as the capture method. The survey was online based and performed at the 'End-of-Day' for a period of a week by the engineers within the company. This survey was performed twice with a gap between the weeks of approximately one month,

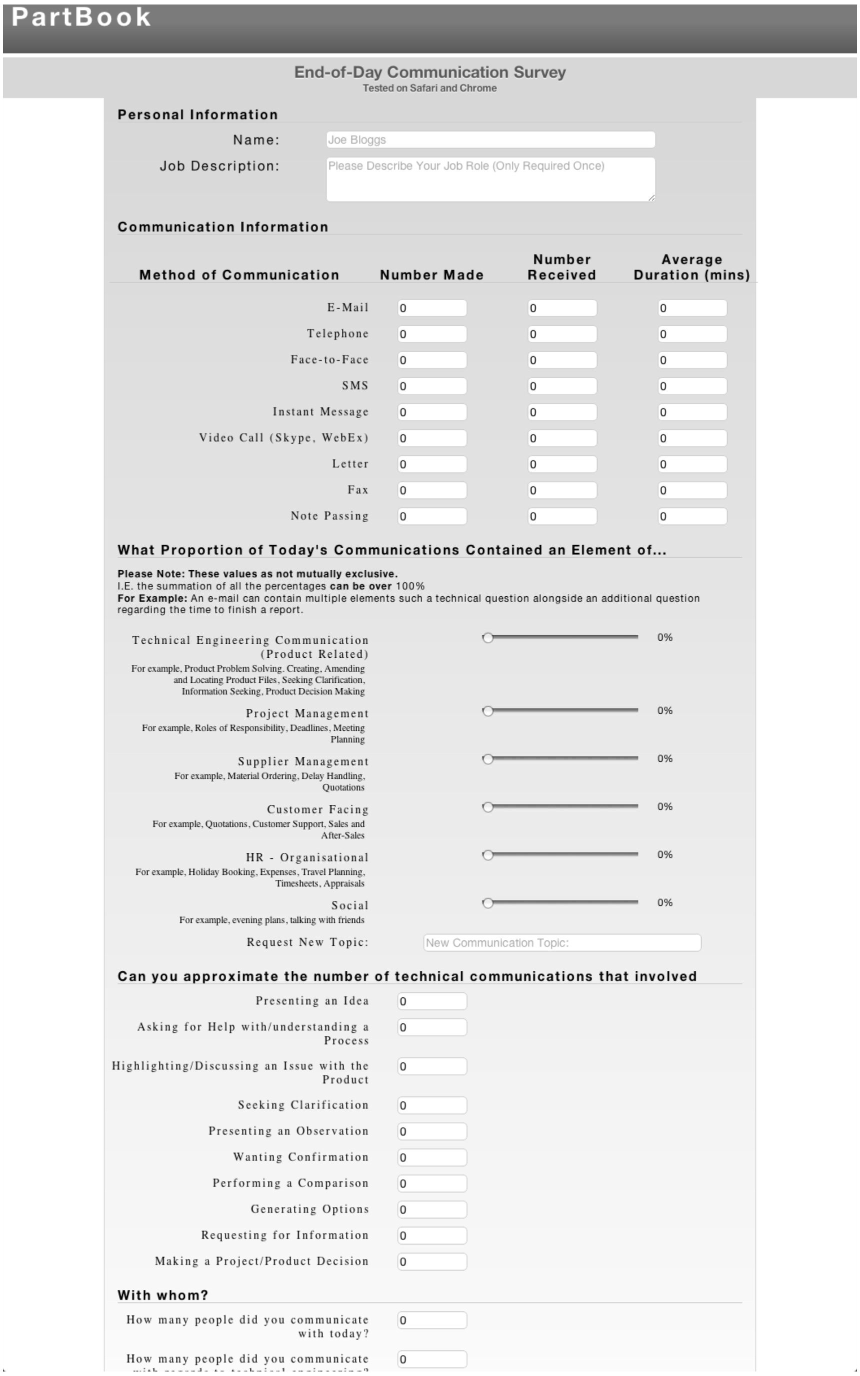
images/removed-4.png

images/removed-5.png

images/removed-6.png

Figure 7.11: Examples of the Products produced by the Company

thus leading to two sets of results, one for each week. Performing the survey twice provides the opportunity to see whether there are considerable differences in communication between working weeks of the company. This is very important as Wasiak et al. [2011] have shown that the proportion of the types of communication varies greatly depending upon the Product Development stage that they are in. The survey is illustrated in Figure 7.12 and covers three areas: Instances, Subject and Purpose of communications.



PartBook

End-of-Day Communication Survey
Tested on Safari and Chrome

Personal Information

Name: Joe Bloggs

Job Description: Please Describe Your Job Role (Only Required Once)

Communication Information

Method of Communication	Number Made	Number Received	Average Duration (mins)
E-Mail	0	0	0
Telephone	0	0	0
Face-to-Face	0	0	0
SMS	0	0	0
Instant Message	0	0	0
Video Call (Skype, WebEx)	0	0	0
Letter	0	0	0
Fax	0	0	0
Note Passing	0	0	0

What Proportion of Today's Communications Contained an Element of...

Please Note: These values as not mutually exclusive.
I.E. the summation of all the percentages **can be over** 100%
For Example: An e-mail can contain multiple elements such a technical question alongside an additional question regarding the time to finish a report.

Technical Engineering Communication (Product Related) — 0%
For example, Product Problem Solving. Creating, Amending and Locating Product Files, Seeking Clarification, Information Seeking, Product Decision Making

Project Management — 0%
For example, Roles of Responsibility, Deadlines, Meeting Planning

Supplier Management — 0%
For example, Material Ordering, Delay Handling, Quotations

Customer Facing — 0%
For example, Quotations, Customer Support, Sales and After-Sales

HR - Organisational — 0%
For example, Holiday Booking, Expenses, Travel Planning, Timesheets, Appraisals

Social — 0%
For example, evening plans, talking with friends

Request New Topic: New Communication Topic:

Can you approximate the number of technical communications that involved

Presenting an Idea	0
Asking for Help with/understanding a Process	0
Highlighting/Discussing an Issue with the Product	0
Seeking Clarification	0
Presenting an Observation	0
Wanting Confirmation	0
Performing a Comparison	0
Generating Options	0
Requesting for Information	0
Making a Project/Product Decision	0

With whom?

How many people did you communicate with today?	0
How many people did you communicate	0

Figure 7.12: The survey performed within the company

7.3.1.1 Instances of Communication by Channel

The engineers were required to enter the number of times they made/received a communication using the various channels listed in Table 7.2. This provides an indication to the level of communication through the company and the proportion taken up by each channel. There are limitations in determining whether a communication continues from one channel to another and whether using a communication was a reply and therefore not generating a new communication topic. However, due to the need for the survey not to intrude too much into the workload and previous surveys using the same metric, it has been deemed suitable for comparative work.

Communication Channels
E-Mail
Telephone
Face-to-Face
SMS
Instant Message
Video Call
Letter
Fax
Note Passing

Table 7.2: Communication Channel Categories

7.3.1.2 Subject of Communication

To understand the variety of communications contributed to by engineers, this paper proposes five subjects of communication (Table 7.3), which are an aggregation of types described by Wasiak et al. [2011], Tenopir and King [2004] & Gopsill et al. [2012]. Engineers were required to indicate proportionally, how many communications contained the following subjects of communication. It was strongly enforced that these proportions were not mutually exclusive and that communications have the potential to have a multiplicity of subjects. In addition, the engineers were given an opportunity to add or request amendments to the definitions of the subjects. The study wanted to see whether these subjects cover all communications within engineering and the ability for engineers to be able to distinguish between them.

Term	**Examples**
Engineering Design Communication	Product Problem Solving, Creating, Amending and Locating, Product Files, Seeking Clarification and Product Decision Making
Project Management	Roles of Responsibility, Deadlines and Meeting Planning
Supplier Management	Material Ordering, Delay Handling and Quotations
Customer Facing	Quotations, Customer Support, Sales and After-Sales
HR/Organisational	Holiday Booking, Expenses, Travel Planning, Timesheets and Appraisals
Social	Evening Plans, Talking with Friends and '*the football last night*'

Table 7.3: Proposed Subjects of Communication

7.3.1.3 Purpose of Communication

As mentioned previously in the synthesis and elicitation of requirements from the literature, there are a number of purposes for 'why' an engineer would wish to communicate with others (Table 7.4). However, this has been aggregated from descriptive studies and thus, the definitions of the purposes have been generated for research purposes to understand the communication behaviour within engineering. It is therefore argued that there needs to be confirmation that engineers understand the concept of purposes as well as being comfortable in classifying their communication by its purpose. In order to see whether this is the case, the survey requests the engineers to approximate the number of communications that they have had during the day that could be classified as one of the types of purpose. There was also the ability for the participation engineers to request and clarify the purposes of Engineering Design Communication.

Purpose of Engineering Design Communication
Idea
Help
Issue
Clarification
Observation
Confirmation
Comparison
Option Generation
Information Request
Decision

Table 7.4: Summary of Purposes of Communication (*Re-iterated from* Table 4.4)

7.3.2 Results and Discussion

Th following section discusses the results from the trial of the prototype tool and survey that was performed within the company. The discussion raises the implications that the study has had on the development of PartBook as well as discussing any potential changes since past research within the field of Engineering Design Communication.

7.3.2.1 Minutes from the Development Meetings

Table 7.5 provides a summary of the key points made in the weekly feedback sessions as the engineers within the company trialled the tool. In addition, the actions arising from the discussion have also been noted for clarity.

Week/ Meeting	**Feedback/Notes**	**Action/Outcome**
One	• The engineers were still becoming familiar with the tool and the meeting became more of a clarification session on the functionality within PartBook.	• No Action Required
Two	• Decrease the size of the communication elements and thumbnails to enable more of the communication to be viewed on the screen. • The arrows indicating the direction of the responses within the communication were difficult to distinguish. • The engineers wished to highlight the engineer who created the communication throughout the communication.	• Decrease the font and thumbnail size of the elements so that more information can be viewed on the screen at once • Placed a star icon next to the name of the engineer who created the communication.
Three	• The uploading of an image proved temperamental and needed to be investigated. • There was some positive feedback on the help pages provided on PartBook and they were uses often by the engineers. Additional screenshots or videos could be used to improve them further. • It was noted that many communications continued after the conclusion statement was made, rather than creating a new communication for the new statements.	• It was discovered that there was a size limitation placed on the University Serves. Therefore a warning was placed as well as prevention of creating a communication with too large a size of image. • Additional screenshots are to be generated for the next study although no videos due to time constraints. • Re-iteration of generating new communication rather than continuing a concluded communication was made.
Four	• It became apparent that many communications were remaining in the response stage and not being concluded. Discussion of this led to the outcome that these communications were never answered and this may due to there not being the knowledge within the companies' engineers. • Although responses were limited, the engineers felt that PartBook was a useful source of highlighting work being performed by fellow engineers and if interested, they would go and speak with that person Face-to-Face such is their proximity. • Finally, a new purpose of communication was suggested and that was one of *Problem Breakdown* where they wished to understand what would be required to solve the problem.	• Added a new purpose to the original set *Problem Breakdown.*

Table 7.5: Feedback and development actions taken during the SME study

7.3.2.2 Survey Results

This section provides the results and discussion of the results from the survey, with comparison to previous research where applicable. The study managed to achieve an 87% return rate for survey one and 50% return for survey two, thus giving a combined return percentage of 70% with an n = 30. The main factors for the drop in return percentage was through engineers being on holiday and/or away from the office. The results are summarised with respect to Instances, Subject and Purpose of communication.

The proportion of communication through the various communication channels of the SME from the aggregation of the surveys from week A and week B is shown in Figure 7.13. Although, the survey presented nine channels for communication to flow, only three were significantly used. It can be seen that E-Mail is the most frequently used communication channel, followed by Face-to-Face and then the Telephone. Looking at the overall proportions of communication made/received, it can be seen that it is consistent between the two weeks. The almost even proportion supports the view of engineering as a highly collaborative activity where instances of communication made/received are even across the company [Bellotti and Bly, 1996]. E-Mail (and more significantly E-Mail received) takes up a high proportion of the instances of communication and as it often used for distributed communication, it is argued that these communications are with external sources for information gathering. In comparison, Face-to-Face made is greater than received and this could be indicative of engineers receiving the majority of information through E-Mail, which is then discussed between colleagues through Face-to-Face.

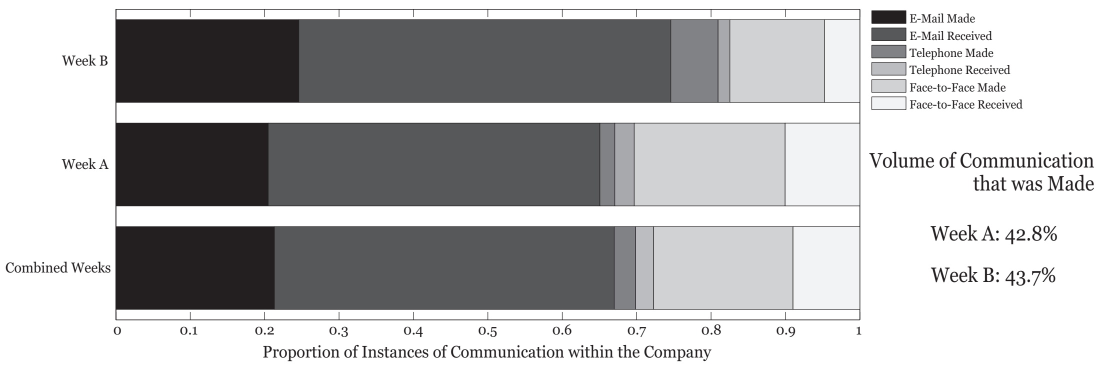


Figure 7.13: The Proportion of Instances of Communication within the Company

Previous research has shown that communicating through Face-to-Face represents 40% of engineers' instances of communication, however the two weeks of surveys have shown a decrease and Face-to-Face now represents approximately 30% of an engineers communication instances [Tenopir and King, 2004]. Vest et al. [1996] highlights that engineers external communication had often been through the use of the Telephone (up to 50%) and the results from this survey shows that Telephones prominence has been greatly reduced and further, as Face-to-Face has also reduced, revealing how important E-Mail has become as a method of communication.

The instances of communication metric cannot be taken as the literal value even though it does provide an indication of the level of use each channel within the company. This is because it is a challenge to be able to know whether one is creating a new communication, contributing to or continuing a communication through an alternate channel. The handling of a communication can vary greatly depending upon the channel chosen and this can aid or hinder the recognition of one creating a new communication, contributing or the continuation of a past communication. In addition, communications may start within one channel and transition to another channel, leading to more confusion. Finally, the accuracy of the capture is limited to the engineers being able to effectively record the number of communications during the day and be able to report them back at the 'end-of-day'. Therefore, the instances of communication metric can only be considered as an indicator of use of the various methods of communication rather than the ability to trace the exact number of communications.

Thus, the key result is that engineers still make considerable use of Face-to-Face (∼30%) alongside E- Mail (∼65%) communication channels, which has taken over the use of Telephone (∼5%) for distributed communications, and that there is an consistent level of making/receiving (43%/77%) communication showing the highly-collaborative nature of engineering within the company.

The proportions of communications for each individual survey across both weeks that contain the various subjects outlined in 7.3.1.2 is shown in Figure 7.14. It is important to re-iterate that the subjects are mutually exclusive and each has been measured against the total communication instances that the engineer has been involved in that day (i.e. What proportion of communications contained subject X?). Therefore, values >100% will indicate a multiplicity of subjects within the communications, 100% would be indicative of single purpose communication and <100% would indicate incompleteness in being able to distinguish the subject/s of the communication.

Week A contained a level of incompleteness and feedback from the engineers proposed two additional subjects of communications; Networking and Continuing Professional Development (CPD). Networking has been described as communication that presents the opportunity to maintain their social network and visibility within the company's social structure. CPD is described as the communications involved in aiding career development through external accreditation (for example, becoming chartered and/or additional qualifications). Placing these within the survey for Week B showed an increase in the summation of the proportions. In addition, no other subjects were requested in Week B and therefore this combination of results provides evidence to suggest that engineers can effectively categorise their communication with the list of subjects. Comparing the proportions of communications containing the various subjects from each individual survey highlights the varied nature of communication of engineers within an SME. This may seem a logical conclusion, as the size of company would require engineers to be involved in many aspects of the companies' activities for them to succeed. Even though there is a great variety in the proportions of subjects, it can be seen that Engineering Design Communication, Project Management and to a certain extent Human Resources are the main subjects that engineers communications contain. Finally, looking across all the surveys, it can be seen that almost all are within the range of 80-120%, which as mentioned previously above, is indicative of most engineers' communication containing a single subject.

Wasiak et al. [2011] analysis of e-mail content within an engineering project shows how the proportions of the types (as referred to in their study) of communications is affected by both the individual and over time, thereby supporting the variety that is present within this result. Tenopir and King [2004] study on an engineers high-level activities are comparable to

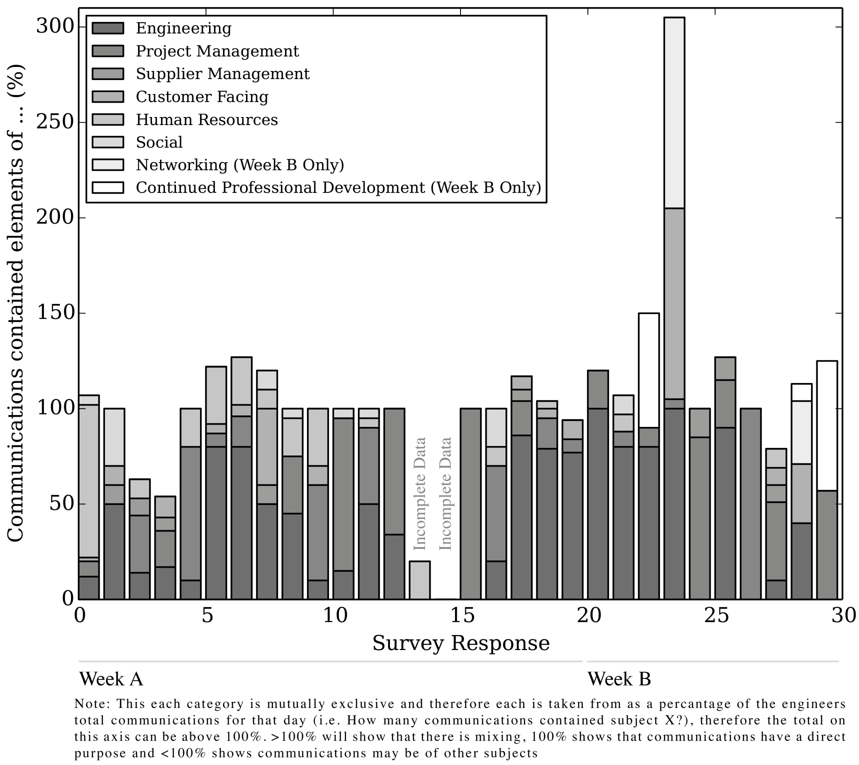


Figure 7.14: The Proportions of Subjects contained within the Instances of Communications for each completed survey

the subjects presented here and the results show that engineering and management activities are the main contributor to an engineers workload and thus, it is logical to see that EDC and Project Management are the main subjects.

In the case of the subject of communication, again there are difficulties in the engineers being able to effectively post-rationalise the communications they have had at the 'end-of-day'. However, ensuring that each subject was considered separately in relation to whole proportion of communications an engineer had during the day. It can be therefore said that the key results are:

- The subjects of communication in Table 7.3 can effectively represent all communications within an SME in 2012.
- Engineering Design Communication, Project Management and Human Resources are the main contributing subjects.
- Engineers' subjects of communication vary greatly from day-to-day, week-by-week.
- Almost all communications are focused upon a single subject.

The proportion of the instances of the purposes behind the creation of an Engineering Design Communication to the total instances of EDCs with weeks A and B expressed separately is shown in Figure 7.15. During both weeks, no suggestions were made to add any additional purposes of the EDCs and thus can be considered as an indicator to the completeness of the purposes proposed in Table 7.4. This is further supported by the engineers making use of all the available terms, which indicates that every term within Table 7.4 is required. In addition, it shows that the engineers were able to distinguish EDC from one another based upon their purpose. These terms could have great potential in being able to organise EDCs within a computer-mediated environment. Comparing the results from both weeks may suggest that there is a consistency in the proportions of the various purposes of EDC being made, however due to the size of the dataset, no statistical significance can be achieved.

Kwasitsu [2003] study on information seeking behaviour shows that approximately 50% of engineers communications involve solving a problem and this is comparable to combining Help (solving a process issue) and Issue (solving a product issue), which is in the region of 25-35%. In addition, communicating an idea, engineers spent around 14%, which is consistent with this study that shows 12-18% of EDCs concerned ideas.

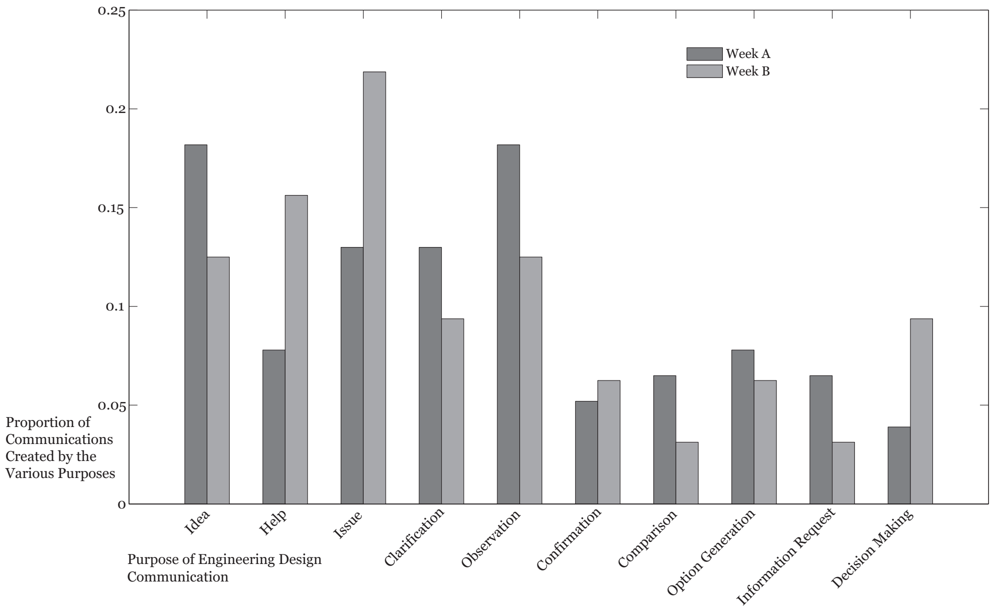


Figure 7.15: Proportions of Purpose of the Engineering Design Communication

The final metric has been the identification of the purpose of each instance of EDC the engineer has had during the day. Again, post-rationalisation and memory may lead to inaccuracies on the level of instance however as this metric considers the engineers thought-process on '*why*' they wished to have an EDC and therefore they are best suited to distinguish their communications by this measure.

Thus, the key results is that engineers were able to distinguish their EDCs against the ten purposes of EDC shown in table 3 and these have further potential for one wishing to support EDC.

7.3.3 Summary of Industrial Study

The industrial study intended to ensure the suitability of PartBook for implementation within a Engineering Project as well as providing an initial check against the literature to determine whether there has been any considerable changes in the communication behaviour of a modern engineering company. Six actions were generated from the feedback session to improve PartBook ahead of the main study, which highlighted some technical as well as usability issues with the tool. The results from the questionnaire supported previous findings from past research as it demonstrated that engineers usually have a single purpose for their communication but also highlights the rise in use of digital communication (i.e. E-Mail). In addition, it demonstrated that there was a level of completeness to the list of purposes that has been generated from the literature.

7.4 Chapter Summary

This chapter has presented the iterative development that has taken place to produce the prototype tool - PartBook - that instantiates the Social Media Approach described in Chapter 6. A Social Media approach that has been built from the requirements to support Engineering Design Communication (Chapter 4) and the consideration in taking a Social Media Approach (Chapter 5). The tool has been developed using web-based technologies, which has enabled the iterative development to be performed within the given timescale and this evolution has been discussed in the first section. Following this, the functionality of the final prototype has been presented alongside how it meets the Social Media features required by the Social Media Approach. As this development had solely been built on the literature, it was important to check some of the key aspects of Engineering Design Communication to ensure that there were no considerable differences to current Engineering Practice. The survey of a Small-to-Medium Enterprise alongside the trialling of the tool with their engineers enabled improvements to be made ahead of the main study.

Chapter 8

Formula Student Study

To validate the requirements set out chapter 4 (Descriptive I) and evaluate through assessing the impact of a Social Media approach with regards to Engineering Work, Records and Project Management, this chapter describes the study that fulfils Descriptive II of the DRM framework.

How does Social Media support Engineering Design Communication?

The study implements PartBook within a Formula Student project at the University of Bath. The use of a Formula Student study is consistent with other studies in the field. The importance of such a project within the education of young engineers has been discussed by Davies [2013], which highlights that Formula Student is the closest to a real-life project that the students have throughout their education as it involves delivery of a product, justification of design choices, collaboration within a team and the management of stakeholder expectations. Many of the previous studies involving a Formula Student project have focused on the implementation of new tools or development of knowledge models, where it is argued that this work also aligns to [Jamshidi and Jamshidi, 2011, Qin et al., 2013, Langer et al., 2011]. Table 8.1 provides a summary of the studies that have used the Formula Student project. It is also argued that the consistent nature of this design project makes it a potentially repeatable study and thus enable the comparison and contrast of Engineering Design Research.

This chapter continues by discussing the context of the Formula Student project, the engineering team involved, the study performed and finally, a summary of the dataset that has been captured. The analysis of this dataset is covered in the following two chapters.

Publication	**Studies using Formula Student**
DESIGN	Pehan and Kegl [2002], Kegl and Pehan [2002]
International Conference on Engineering Design	Qin et al. [2013], Stetter et al. [2011], Stetter and Phleps [2011]
International Conference on Product Lifecycle Management	Jamshidi and Jamshidi [2011], Langer et al. [2011]
Journal of Engineering Design	Davies [2013]

Table 8.1: The use of Formula Student in Engineering Design Research

8.1 Study Context

> "Our mission is to excite and encourage young people to take up a career in engineering. It seeks to challenge university students to conceive, design, build, cost, present and compete as a team with a small single-seat racing car in a series of static and dynamic competitions. The format of the event is such that it provides an ideal opportunity for the students to demonstrate and improve their capabilities to deliver a complex and integrated product in the demanding environment of a motorsport competition."

Formula Student Mission Statement

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Figure 8.1: Formula Student Car (*Source*: TBR)

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[1], Australia and Europe. Teams of students from their respective universities are placed in charge of designing, developing and manufacturing a single-seat race car to compete within the various challenges setout by the competition (Figure 8.1). This is also a highly multi-disciplinary and collaborative environment involving the expertise of students undertaking various engineering courses such as aerospace, automotive, electrical, manufacturing and mechanical. The judging of the competition is not only based upon how the car performs at the event but also how the team can provide and deliver the rationale behind *'why the car they have designed is the way it is'*. Figure 8.2 show the judging sheet to that effect.

In the case of the team at the University of Bath, hereby referred to as Team Bath Racing (TBR), a group of third year students are selected to participate in the Formula Student Competition, who are then tasked with the design and development of the car. 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 entries are required to present their proposed race cars to a board of experts within the Motorsport field. Figure 8.2 provides an example of the design judging sheet used to assess the entries during this day and it can be seen that the marking criteria is strongly aimed at the participants being able to demonstrate the reasoning behind their designs.

[1] referred to as Formula SAE

Formula Student 2012 **Design Judging Score Sheet (Class 1)**

University: **Car No:** **Weight (kg):** **Judging Team:**

Max Points	Assessed Area	Points Awarded	Comments (Judges to highlight particularly strong or weak aspects of the design in each assessed area)	
10	**Design Report Score** (quality of pre-submitted report)	10		
25	**Overall Vehicle Concept** (Conceptual appeal, benchmark data, risk analysis, overall appearance, choice of basic concept, mass. Justification of powertrain option chosen)	25	**GOOD**	**POOR**
15	**Overall Integration of Development** (Build quality, preparation, integration and verification of all sub systems)	15	**GOOD**	**POOR**
15	**Driver Environment & Low Voltage Electrical Systems** (Controls, ergonomics, safety, low voltage wiring, driver display)	15	**GOOD**	**POOR**
20	**Chassis Design & Development** (Frame & structural aspects, fundamental engineering, e.g. load paths and safety. Suspension, steering and brakes)	20	**GOOD**	**POOR**
30	**Powertrain Design & Development** (Engine, hybrid system, high voltage electrical system, possible alternative fuel optimisation. Transmission and drivetrain. Safety considerations)	30	**GOOD**	**POOR**
20	**Practical Design Aspects** (Design for profit, manufacture, servicing and adjustability, fitness for purpose for customer)	20	**GOOD**	**POOR**
15	**Application of Engineering Science** (Effective use of innovation, advanced analysis, IT design & development, information sharing)	15	**GOOD**	**POOR**
	DEDUCTIONS (- 50 max) **Only use for carryover parts OR overall lack of knowledge**	-50	**Overall Summary Good**	**Overall Summary Poor to work on**
150	**TOTAL (before moderation)**	100		

- *Up to 50 points may be deducted for too much carryover of last year's car and/or lack of understanding of the design, development, manufacture and costs of the car. 25 points may be deducted if the car fails to start at least one of the dynamic events.*

Form completed by (write name in BLOCK CAPITALS): ____________________

Figure 8.2: Design Judging Sheet for Class 1 FS Cars (*Source*: FS Website)

8.2 The Team

The 2013 Team Bath Racing is made up of 33 engineering students from various courses as shown in Table 8.2, thus revealing the multi-disciplinary nature of the team and project. Ahead of the main study, a brief profiling of the team was conducted through a questionnaire to elicit their experience with web-based tools (See Appendix A). The results from the questionnaire show that 94% of the respondents utilise cloud based storage for documents and all had used at least one Social Media tool with the majority having used two. 88% of the respondents had either 4-6 or 7-9 years worth of experience using Social Media tools.

Course:	**No.**
Mechanical Engineering	17
Automotive Engineering	13
Integrated Mechanical & Electrical Engineering (IME)	3

Table 8.2: Courses undertaken by the students in Team Bath Racing

The Formula Student project is primarily run at the University and in the case of the TBR team, there is allocated workspace. Therefore, it may be argued that the study is not one of a distributed team but of a collocated team. However, Figure 8.3 shows the main flows of internet traffic visiting PartBook over the period of the study and shows that there must have been cases where some members of the team were working away from their allocated workspace. It is interesting to note the 30% of the traffic has come from the London area although one has to recognise that the traffic is passing through main network hubs and therefore this may be traffic for the South East region of the country. Although, this does provide evidence to show that the project has an element of geographical distributed working. This is further confirmed by Figure 8.4a showing that there were a high number of unique IP addresses used throughout each week, which indicates access from multiple locations although it may also be the case that some may not have static IP addresses and therefore the traffic could be from the same location. Also, 8.4b shows that both E-Mail and PartBook communications continued passed the typical hours of a working day. Therefore, it is argued that the students continued to work at home during the evenings, which necessitated continued discussion. It is interesting to note that approximately 30% of the communication from the team occurred after 6pm. From this analysis of user activity, it can be said that the study is one of a distributed team.

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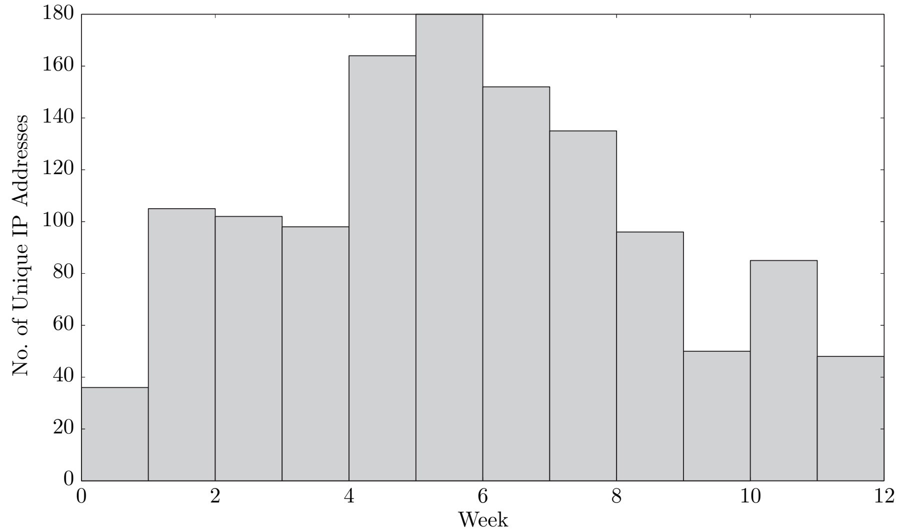
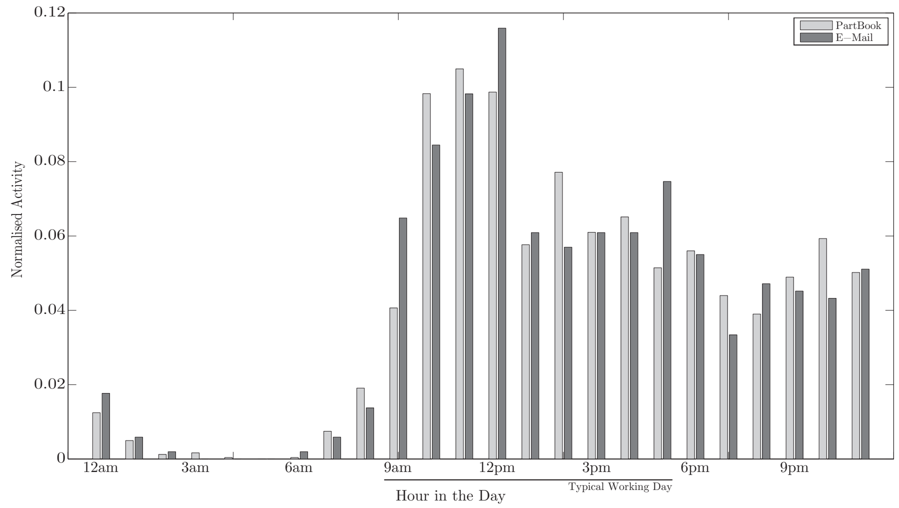
Figure 8.3: Internet traffic visiting the PartBook Website



(a) Number of unique IP addresses accessing the tool per week



(b) PartBook and E-Mail Communication Activity per hour

Figure 8.4: Engineer communication activity

8.3 The Study

The study is one of full disclosure, whereby the students are fully aware of the research project and this has been performed by presentations given before the start of their project [Peterson, 1999]. The team had the opportunity to refuse to use PartBook. However, as they saw the potential in demonstrating their rationale in the competition using the tool, they deemed it suitable to trial the tool. The study took place over an eleven week period with the first two weeks focused on showing the students the features of the tool. Weekly feedback sessions were held to discuss the use of PartBook and whether there were an technical issues.

In order to validate the requirements for supporting Engineering Design Communication (Chapter 9), a questionnaire and structured interviews were used at the end of the eleven week period that provided to elicit the validity of the requirements from the engineers perspective. In addition, the communications captured by the PartBook tool itself were also analysed. This enables triangulation of results from various sources to occur and therefore provide enough evidence to conclude the requirements validity [Jick, 1979]. It is also important to use multiple methods of data capture as this study is one of the 'real-world' where may outside influences might affect the results [Robson, 2002]. A more in-depth description of each data capture method is now discussed.

8.3.1 Questionnaire

The questionnaire was provided to all the engineers involved and had been designed to elicit user feedback on the functionality provided by the tool. As the user-group were unaware of the requirements and rationale behind their development, it is important to elicit responses to the requirements with respect to the context of using PartBook. Table 8.3 provides and example of some of the questions that relate to a specific requirement and is placed within the context of using PartBook.

The analysis of these results provides an indication as to requirements validity from a general user perspective. In addition, the questionnaire also assesses the usability of tool through the System Usability Scale (SUS) in order for the potential usability issues to be taken into account when analysing the engineers responses. Some additional background information concerning the participants with regards to their usage of current Social Media tools in order to elicit their level of experience with such tools. The complete full questionnaire can be viewed in Appendix A and totals 47 questions.

PartBook Questionnaire	**Refers to Requirement**	**Type**
The purpose tag helped me understand what the engineer wanted from the communication.	RQ11	Lickert Scale (1-9)
The response tags helped me understand the statements being made within the communications.	RQ12	Lickert Scale (1-9)
The conclusion tag helped me understand the outcome of the communication.	Lickert Scale (1-9)	
The images aided my understanding of the communication.	RQ1	Lickert Scale (1-9)

Table 8.3: Exemplar Questions from the Questionnaire

8.3.2 Structured Interviews

Structured Interviews conducted with a subset of engineers, namely the Project Leader, PartBook Liason Engineer[2] and a PartBook user who had a high level of activity on the tool. Each were worked closely with the researcher to implement PartBook within the project and who had a deeper understanding of the requirements that related to features present within the tool. Therefore, these participants are able to provide a different perspective to the validity of the requirements when compared to the wider group. In order to take advantage of this, a structured interview process was used where each of the three participants were given an opportunity to rate the 'validity' of each requirement and consideration in their opinion. In addition, they were also able to provide potential amendments to the requirements/considerations

[2]The student within the team who had the responsibility to oversee the use of PartBook within the team

or explicitly request new requirements/considerations.

8.3.3 User Activity

In addition, all e-mails sent pertaining to the project were stored in a shared mailbox so that a comparison between E-Mail and PartBook could be made. Although, it is conceded that there were many other communication tools/methods also being used by the students but unfortunately they were not able to be captured (See Figure 8.5). Also, the evolution of the file structure of their shared workspace was captured using a Raspberry Pi and separate RAID storage. The python code (developed by the author) checked the file structure of the shared drive every 20 minutes and it would note any changes to the structure and files. If a file had changed, a copy of the file would be made to the RAID storage. Thus, enabling comparison of the files as they evolved during the project. This enables insights to be drawn from the communications being had and the potential changes in the records being generated. The analysis of this large dataset provides the ability to assess the impact of the tool with regards to Engineering Work, Engineering Records and Engineering Project Management and therefore forms the evaluation of the Social Media Approach (Chapter 10).

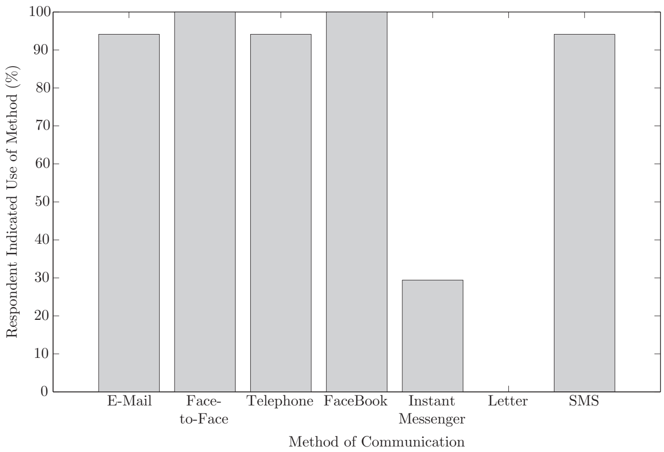


Figure 8.5: The Communications Tools/Methods Used in TBR13 apart from PartBook

Table 8.4 provides a summary of the dataset created by the above methods.

General Information
• 34 students were involved in the 2013-2014 Formula Student project.
• The study commenced in March 2013 and ended June 2013. A total of 11 weeks of information was captured.
Questionnaire Background Information
• The questionnaire was 43 questions long.
• 57% return rate on the questionnaire.
PartBook Information
• 488 communications took place on PartBook.
E-Mail Information
• 509 e-mails were sent in this period.
Engineering Records Information
• 13,459 unique files have been created over this period.
• The current shared file space size has reached 100.58 GB

Table 8.4: The Structure of the Results

8.4 Usability vs Functionality

PartBook received an average score of 56.3 which places the tool in the 20th percentile, thus there was a lack of usability with PartBook in its present state. Although, Figure 8.6 shows a box plot of the respondents SUS scores and it does appear to vary greatly. This may be an indicator that the tools functionality may not have been explained fully and coherently to all the students. Figure 8.7 show how the overall summation of the scores from the PartBook questions (with the higher number indicating greater agreement with the requirements) varies in relation to the SUS score. There appears to be a slight correlation between the two values indicating that the usability of the tool did impact the responses given. However, no statistical significance could be generated due to a relatively low N number even though it is considered reasonably high in this field. Although, having this analysis and insight provides a clear indication that usability may be a significant factor on the questionnaire and interview results.

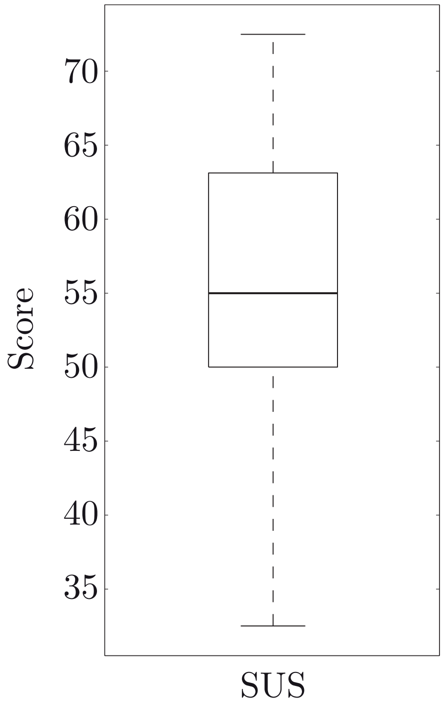


Figure 8.6: Systems Usability Scale Score from Respondents

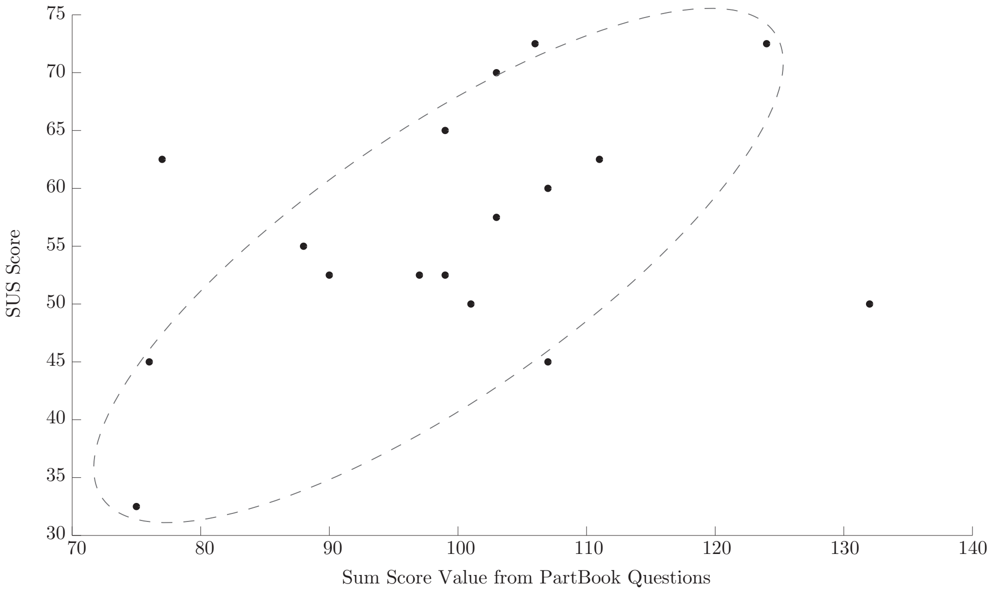


Figure 8.7: Potential correlation between SUS score and feedback given in the questionnaire

8.5 Chapter Summary

This chapter has discussed the suitability of using a Formula Student study as the validation and evaluation case for supporting Engineering Design Communication through a Social Media Approach. The context of the Formula Student with respect to the University of Bath team has been made and it has been highlighted that the project is indeed multi-disciplinary as well as geographically distributed. Details of the study alongside a description of how the data has been captured have been given, which is one of multiple methods to ensure enough information is available for validation and evaluation. This in turn, led to a summary of the dataset that has been generated. A discussion on the usability of the tool has been made, which highlights that it may play an impact factor in the results provided by the questionnaire and interviews.

Chapter 9

Validating the Requirements & Social Media Considerations

As the Social Media approach has been built-up from the need to meet the requirements to support Engineering Design Communication and the considerations when taking a Social Media approach, it is important to ensure the validity of these aspects. As mentioned previously in the literature review the, validation is the analysis of theory to ensure that it reflects reality. In this case, the research needs to check whether the requirements suitably reflect what is required in order to support Engineering Design Communication. In addition, the considerations towards the application of Social Media also need to suitably reflect reality.

9.1 Data used for the Validation

In order to achieve this, the study has been one of total disclosure. Therefore, the engineers were made aware of the requirements and considerations that the tool had been based upon. At the end of the eleven week period, the PartBook liason, Project Leader and an engineer who spent a significant amount of time using the tool (PartBook user) were selected to run through each of the requirements and considerations and to rate (1-5) how the tool met them as well as having the opportunity to comment and provide potential amendments. Thus, providing insights into their validity.

In addition, a questionnaire has been sent to all the engineers involved in the Formula Student project with questions that reflect the reasoning for a requirements existence as well as a rating of the features within the tool. A 57% return rate was achieved and the results are presented in the following figures. Figure 9.1 presents a box plots produced by the feedback given with respect to each statement made by the questionnaire, whilst Figure 9.2 shows the highest and lowest rated features. Figure 9.3 provides an insight into which perspectives the engineers would of likely used if they were to search & retrieve communications. In addition, Table 9.1 presents the purpose-response matrix generated from the data stored in PartBook. This is similar in style to Table 4.6 albeit containing the values and percentages of the use of the various types of purpose and response as well as the additional types created by the engineers during the study.

These results form the basis by which each requirement/consideration will be validated.

Alongside this, specific results will be presented within the appropriate section that provide further evidence that can aid the validation of the given requirement/consideration. From the discussion of these results in relation to the requirement/consideration, this work will argue its position in either one of four levels of validation that is used within this thesis:

Valid
: Both, results from the use case & user opinion indicate that the requirement/consideration should be met in order to support Engineering Design Communication.

Partially Valid
: Either the use case or user opinion but not the other of results gathered provide an indication that the requirement/consideration should be met in order to support Engineering Design Communication. The results may provide a potential amendment to the requirement/consideration.

Not-Valid
: None of the use case or user opinion results indicate that the requirement/consideration should be met in order to support Engineering Design Communication.

Insufficient Data
: The use case and user opinion did not provide the results in order to assess the validity of the requirement/consideration.

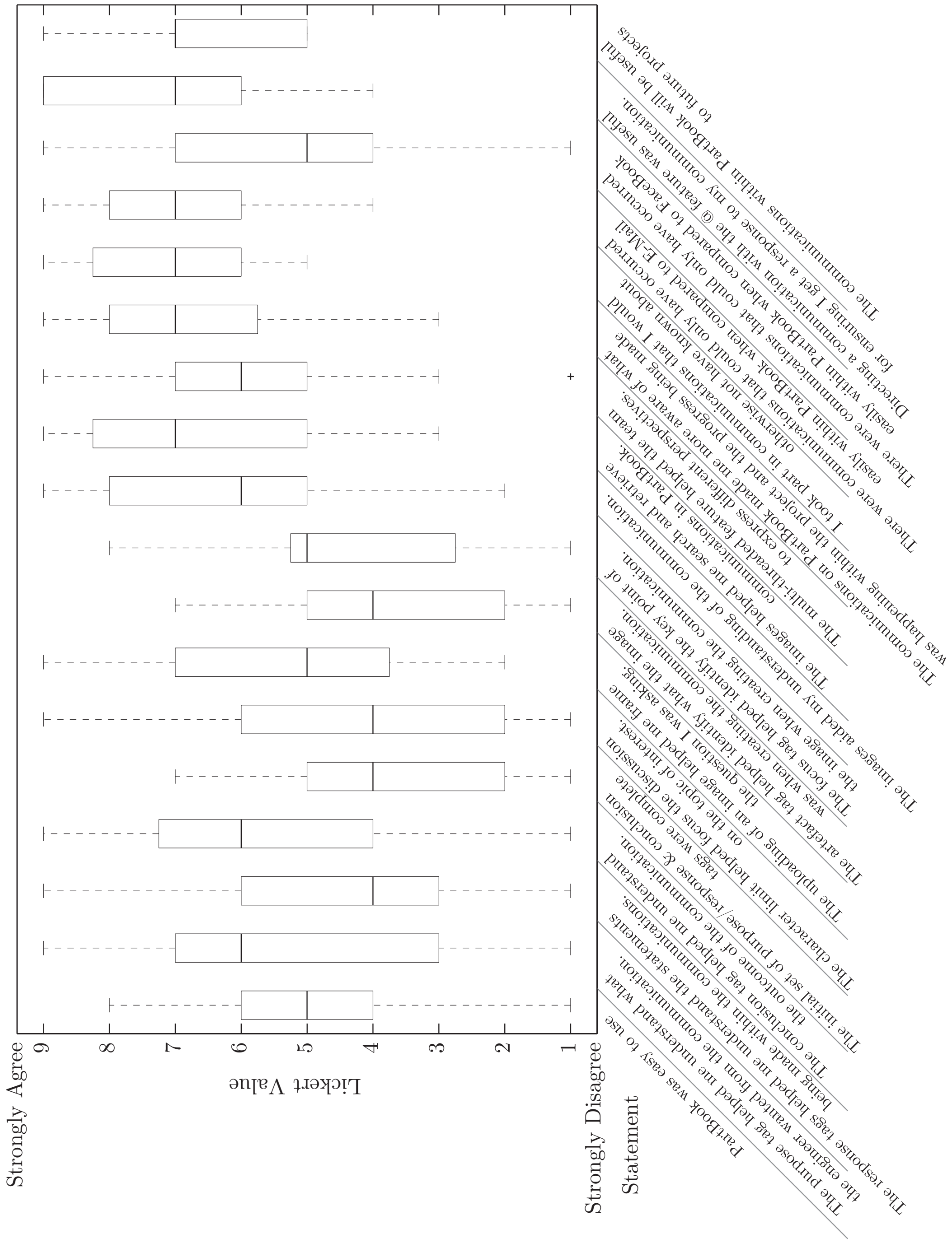


Figure 9.1: The Aggregated Response from the Questionnaire

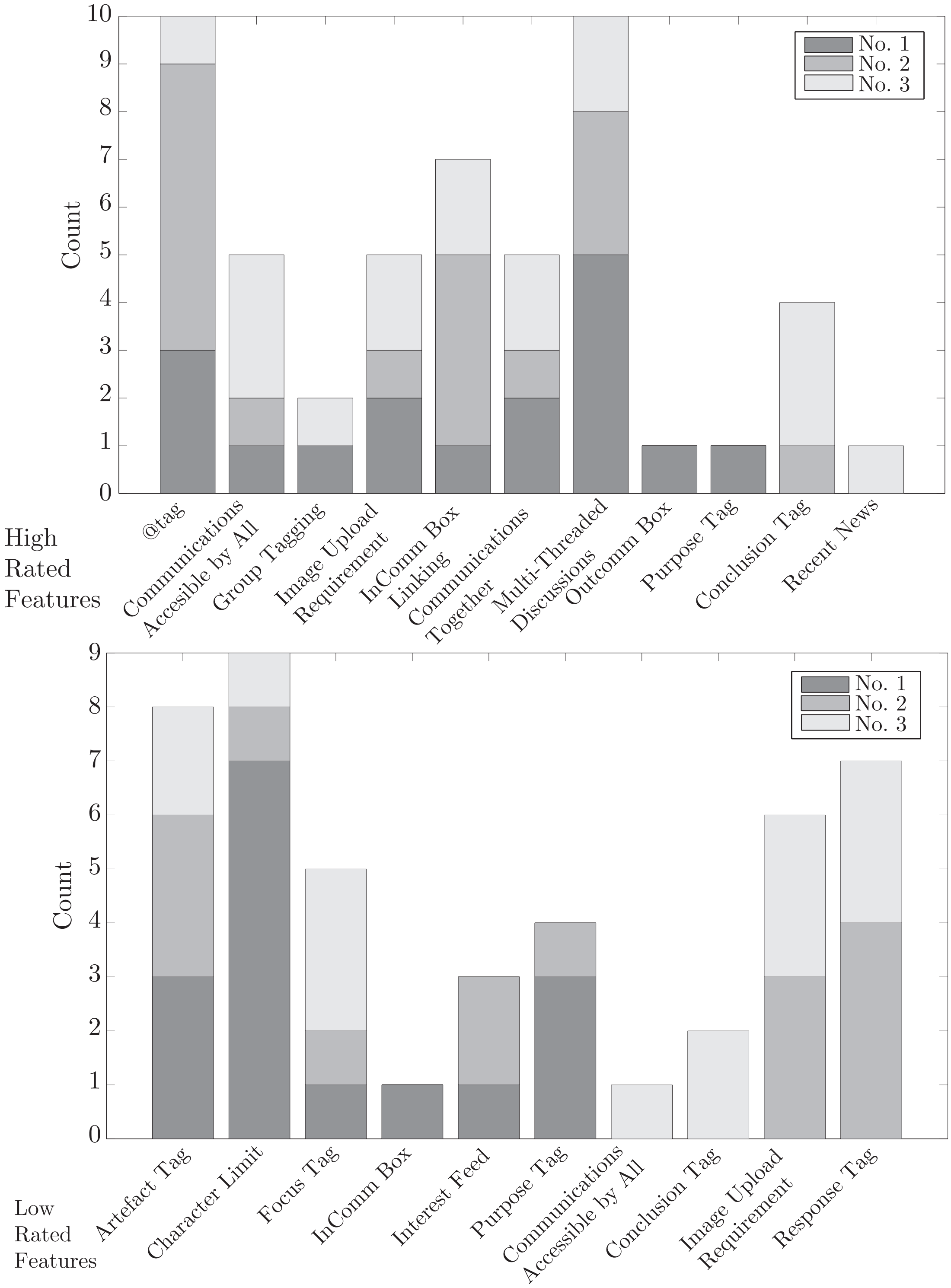


Figure 9.2: The Highest and Lowest Rated Features of PartBook

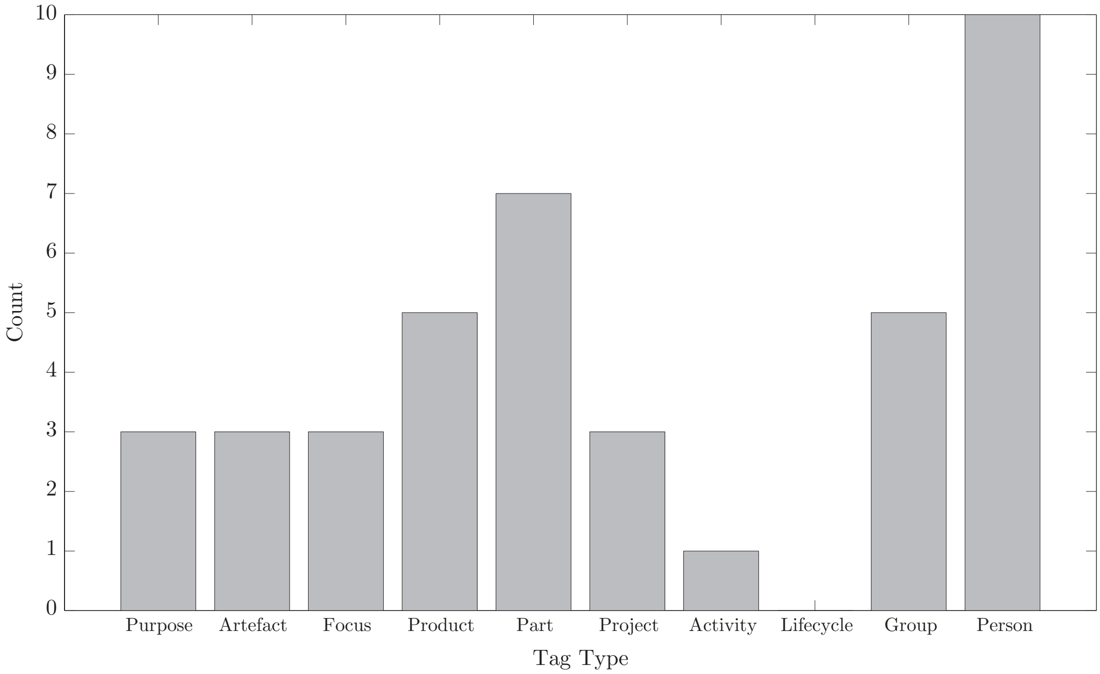


Figure 9.3: The perspectives that the respondents indicated they would use for future Search & Retrieval

Response Types	Purpose of the Communication (No. of Instances, %)																										
	Idea (50, 10.2%)	Help (31, 6.4%)	Issue (11, 2.3%)	Clarification (41, 8.4%)	Observation (31, 6.4%)	Confirmation (28, 5.7%)	Comparison (17, 3.5%)	Option Generation (1, 0.2%)	Information Request (63, 12.9%)	Decision (10, 2.0%)	Problem Breakdown (5, 1.0%)	PartBook Test (3, 0.6%)	Project Management (6, 1.2%)	Discussion (117, 24%)	Chassis Update - Front Wing (4, 0.8%)	Fixing Good Practice (6, 1.2 %)	Sponsorship (8, 1.6%)	Meeting (4, 0.8%)	Action Required (32, 6.6%)	PartBook Suggestion (3, 0.6%)	Cost Report (2, 0.4%)	Suspension Packaging (1, 0.2%)	Justification (3, 0.6%)	Suggestion (4, 0.8%)	Design Guide (4, 0.8%)	Guide (2, 0.4%)	Manufacturing (1, 0.2%)	**Summation (488)**
Action[1]	14	4	6	12	4									3														43
Action Required[1]														6														6
Addition[2]													8															8
Additional Information[2]																	21											21
Affirmative[3]	8	5	2	8	5														9									37
Agree[4]							9			17									9									26
Clarification[5]														5														5
Conclusion[6]									1																			1
Confirmation[7]						9			48					32														89
Correction[8]	2								5					32														7
Disagree[9]						1				0																		1
Discussion[10]	15					8			37					190		8												258
Enquiry[11]																			2									2
Experience[12]	21	7	8	9	10	8	1	43						21						15								154
Further Details[2]											5																	5
Further Information[2]																								4				4
Guidance[13]	9	6	1	13	4																							33
Help[14]	4																									1		5
Idea[15]	23		3		15			4			13			3														61
Information Location[16]															2													2
Information Locations[16]														10														10
Location[16]	1	3		2					11																			17
Negative[17]																			1									1
Not Valid[18]						0				0																		0
Notification[19]																						4						4
Observation[20]	14	16	10	17	27		15	0						50														149
Opinion[21]	46	32	18	29	22	28	7	1	76	10				71	3					4								347
Other[22]			2							12																		14
PartBook Help[23]		4			4				9			2		1						7								27
PartBook Test[23]														4														4
Question[24]			1	6		6								15					3									31
Response Request[25]									4																			4
Schedule[26]																		4										4
Seriously[27]																			16									16
Summary[28]																										2		16
Supporting Evidence[2]														3														3
Tag[29]															1			2	4									7
Thanks[3]															3													3
Understood[3]													3															3
Valid[30]						2				2																		4
Warning[31]		0	2	2																								4
Work in Progress[32]																			17									17
WTF[33]																			2									2
Summation	143	95	52	97	90	73	33	6	234	41	18	2	11	414	9	8	21	6	54	22	4	4	0	4	0	3	0	

Legend
Original Items
Proposed Associations
User Generated Associations
Note: Superscripts used to group like responses together

Table 9.1: Purpose and Response Types Association Matrix

9.2 Validation of Requirements

This section provides the results and discussion of validity for each of the requirements for supporting Engineering Design Communication.

9.2.1 Requirement 1

To capture a high quality representation of the originating Engineering Record relating to the communication.

Table 9.2 details the information provided by the three participants assessing the validity of requirement one. With an average score of just over 3, it shows that they were unsure how valid the capturing of a high-quality representation of the originating Engineering Record relating to the communication was. Taking a look at the questionnaire, the result from the statement '*the upload of an image helped me frame my discussion*' shows that the students neither agreed or disagreed although there is a slight positive skew potentially meaning that a minority found it particularly useful in the disparity in the high/low rated features where the use of an image appears in both. Upon informal discussion and feedback, it was highlighted that it was the time taken to create & upload the image that proved the greatest distraction and better usability would improve this.

Therefore, it is argued that this requirement has been partially validated in that the capture of a representation of the Engineering Record does support Engineering Design Communication in some cases but not all. Usability issues may be a reason for it not being favoured by the engineers. Therefore, further work is required to understand how representations of engineering records should be used to support Engineering Design Communication.

Participant	Score	Comment	Amendment
PartBook Liaison	4		
Project Leader	3	It did capture the topics typed, but lots of topics were not put on there as they happened in conversations ans were never recorded	
PartBook User	4		

Table 9.2: Interview Results for Requirement 1

9.2.2 Requirement 2

To record changes to the Engineering Record as a consequence of the communication.

Table 9.3 presents the results from the respondents in response to requirement two. The PartBook Liaison and User present a consistent viewpoint highlighting that representing the communication in the manner that PartBook has, does help them understand the work that has occurred on the Engineering Record of interest. Although, the Project Leader highlights that due to limited participation by some of the team, not all communication pertaining to an Engineering Record were recorded by the tool. This issue leads to the conclusion that this requirement has been partially validated as the tool was able to record the changes yet issues with participation meant that the potential in understanding the entire evolution of an Engineering Record was not possible. Although, it is contended that no communication tool will ever record all forms of communication and therefore one has to be always aware that the dataset is only a subset of the rationale and information shared within a project.

Participant	Score	Comment	Amendment
PartBook Liaison	5	Easy to see changes and WHY they occurred, not always possible in emails	
Project Leader	2	5% of conversations were documented properly with input from all relevant parties, however off part-book communications were still required as participation was not 90%+.	
PartBook User	4	Easy to track progress and analyse the changes with time reference.	

Table 9.3: Interview Results for Requirement 2

9.2.3 Requirement 3

To enable contributing engineers to embed a representation of an artefact in their responses.

Table 9.4 shows that the participants were unsure of the validity of requirement three. Analysing the comments and amendments, all participants mentioned that there may be cases where more than one representation would be required in the response. The Project Leader also highlighted a usability issue with the tool that may have skewed the result. It is also interesting to note that approximately 30% of the communications within PartBook included a reply containing an additional representation even though there was not a requirement to do so. It is argued that this shows that there is indeed a need for engineers to present supplementary representations as they had to overcome the difficulties in the creation and uploading of the representation.

Therefore, it is argued that this requirement is partially validated as the results show that it is important to provide additional representations despite the usability issues. Although, a potential amendment would be to '*enable contributing engineers to embed one or more representations of an artefact in their responses'* as highlighted by the PartBook user.

Participant	Score	Comment	Amendment
PartBook Liaison	3	More than one photo could be needed and/or supporting documents (like email attachments)	
Project Leader	4	Photos were a good idea to enforce, it was fun and informative. The file size restriction was an issue which was time consuming to alter before uploading.	
PartBook User	3	Not adequate in terms of visually referencing the idea or an analysis.	Ability to attach multiple documents, images and etc...

Table 9.4: Interview Results for Requirement 3

9.2.4 Requirement 4

To provide a text based description of the Engineering Record.

Figure 9.2 shows the feature to tag the representation by its type proved to be one of the least favoured features of PartBook. This is further highlighted by the responses to the statement, '*the artefact tag helped identify what the image was when creating the communication*', which received a relatively low-level of agreement as well as a negative skew thereby highlighting that some did not find it useful at all. The informal discussion of these results led to the outcome that in this case, the representations were enough for them to understand the type of record they were looking at and therefore they did not see the need to explicitly indicate the type. However, Figure 9.3 does reveal that some of the engineers would use it as a means to search & retrieve communications. Thus, highlighting its potential re-use value.

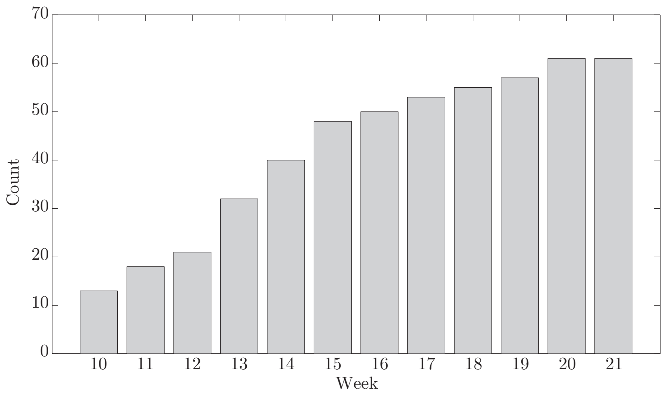


Figure 9.4: Cumulative generation of Engineering Record tags

Reviewing the results from the interviews and specifically focusing on the requirements (Table 9.5), The comments made by the participants are more related to the creation of the statement text and not the creation of a tag related to the Engineering Record. Therefore, the information cannot be used to validate the above requirement.

It was also noted that the list of records became large very quickly and therefore difficult to use with the number of terms quintupling (Figure 9.4). A suggestion was that the file type indicated by the URL provided for digital representations could be used to constrain the types of representation listed (i.e. a .par file already provides a good indication that the representation is of a CAD part). Therefore, it is argued that this requirement has been partially validated and should be amended to reflect this: To provide a semi-automated predictive text-based description of the Engineering Record.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	4	140 character limit principle was good intention for concise record, however too short. an edit comment button would have been useful for typos	
PartBook User	3	Clearly trackable conversation structure	

Table 9.5: Interview Results for Requirement 4

9.2.5 Requirement 5

To record/capture the foci of a communication with respect to the Engineering Record

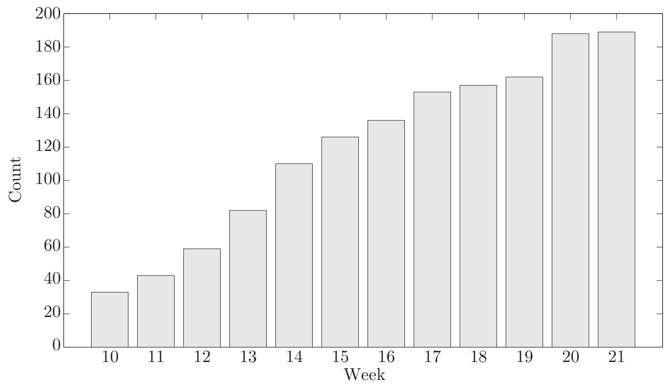


Figure 9.5: Cumulative generation of foci tags

Recording the foci of the communication was achieved in the same manner as the artefact tags. They appeared as a subset of tags once the Engineering Record tag was selected. The use of the focus tag to capture the foci of the communication with respect to the Engineering Record received a similar although less negative response when compared to the previous record tag. The responses to '*the focus tag helped me identify the key point of the image when creating a communication*' showed the majority were indifferent with the statement although the negative skew suggests that a minority disagreed. Informal discussion of these results highlighted that in contrast to the above record tag, the engineers understood the reasoning for this tag and that there could be no automation. As with the 'record tag', the growth of terms also quintupled during the study, which raises issues in the utility as a filter for future search & retrieval. In addition, 187 foci tags were generated and 167 tags were unique, which highlights that there may be limited similarity of tags between the various Engineering Records.

The results from the interviews focusing on the validity of the requirements (Table 9.6) further highlights the issue of categorising by foci, and mentions the issue of a large set of tags being user created. The results also suggest that the tags should be predefined before the start of a project, potentially during the project planning stage.

Therefore, rather than a description of the foci, it was suggested that the ability to highlight specific areas on the representation would have been sufficient for them to deduce the focal point upon the representation. As well as reducing the burden of generating a suitable tag to describe it. Thus, the requirement should be changed to: To highlight the specific area upon the representation relates to the foci of the communication.

Participant	Score	Comment	Amendment
PartBook Liaison	4	Tags/categories could have been easier to see/select	
Project Leader	3	Categories were user created and hence no one was sure where to look. Now we know that categories we need we should have fixed categories	
PartBook User	4	Categorisation is needed for quicker and easy access to desired section of project one needs to be contributing to.	Separate Tabs with project groups. eg: Chassis, Powertrain in different tabs

Table 9.6: Interview Results for Requirement 5

9.2.6 Requirement 6

To provide an electronic or physical reference to the Engineering Record.

Table 9.8 highlights that the two out of the three participants felt that requirement 6 was a valid requirement and did not have any further comments to make. The project leader noted that if one were to attempt to search for communications against a particular Engineering Record, it was not possible to do so easily within the tool. Although potentially an aside to supporting Engineering Design Communication is that it also important to note the potential for re-use of Engineering Design Communications and that you may wish to search on many of the facets captured by it. This is an area of potential future work.

Statement	Value
Total Number of Communications that contained a reference to a record	154 (32%)
Number of Communications that used the URL link functionality	60 (12%)
Number of communications that contained a reference to the shared network space within the textual response	26
Number of hyper-links within the communications that were in the textual elements of the communications	68
Number of communications that used hyper-links within the text and did not use the URL link functionality	66

Table 9.7: The Number of References Made to Records within the Communications

Looking at the analysis of the PartBook dataset, Table 9.7 provides some details on the provision of an electronic or physical reference to an Engineering Record. Almost a third of communication contained a reference to a record through either using the add URL feature or by simply placing the link within their response. This is a particular affordance arising from using a web-based tool. Thus, it is important for the purpose of this validation to say that it was used by the engineers.

Therefore, it is argued that this is a valid requirement in order to support Engineering Design Communication. The results have also highlighted potential future work in how the capture of these communications could be re-used in Engineering Design.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	3	No Search function meant only familiar users could use memory to locate threads via the picture and rough time frame	
PartBook User	5		

Table 9.8: Interview Results for Requirement 6

9.2.7 Requirement 7

To enable engineers to 'push' communications to one another.

Table 9.9 showed that two of the three participants felt that this was a particularly valid requirement in order to support Engineering Design Communication. The project leaders score of three may be justified against the need for the tool to provide a list of names to ensure no miss-spelling occurs and that the functionality works as required. This highlights a usability issue in the current tool and potentially a consideration when using Social Media. That being, to include the functionality for users to select from a pre-defined or evolving set of tags.

Looking at the additional results, the ability to provide a notification to an engineer of a communications existence proved to be one of the most favoured features of PartBook (Figure 9.2). 76% of the communications within PartBook contained at least one @(engineer) tag and 29% of all the creation and response elements within the communications used the @(engineer) tag. Further highlighting its utility within the tool. The response to the statement *directing a communication with the @ feature was useful for ensuring I get a response to my communication* had a highly positive agreement with a positive skew, which confirms that the students felt it was a crucial feature of the tool. During the use of PartBook, a response element termed *response request* & *notification* was generated, which was used to notify and encourage a response from other engineers. Taking these results into account, an additional requirement is proposed: To direct the communication to at least one other engineer during its creation. This is to ensure that an engineer will receive a response once they have created a communication.

Therefore, it is argued that this is a valid requirement in order to support Engineering Design Communication. The results used to discuss its validity have also generated a new consideration and requirement.

Participant	Score	Comment	Amendment
PartBook Liaison	5	Tagging works well	
Project Leader	3	tagging when on a pre set list worked well. just typing in a name gave potential for miss-spelling names	
PartBook User	5		A set group of 'tag' names needed to avoid confusion

Table 9.9: Interview Results for Requirement 7

9.2.8 Requirement 8

To enable engineers to group communications by task.

Only six task groups were created throughout the eleven week study and for each task created, only one communication was assigned to it. This reveals that task groups were not used within this study. Although, the results assessing the validity of the requirements (Table 9.11) contain no comments, yet high scores were given. This hints that it could be a potentially useful method of categorisation. This is also supported by the fact that the students felt that group tags would be a useful means for searching and retrieving past communications (Table 9.3). Thus, it is difficult to assess its validity due to lack of use, although it could be said that it is partially validated as the participants have noted its potential utility in supporting Engineering Design Communications.

Task Group Names
cockpit
tshirt
weeks. i suggest a better foc
powertrain
castle combe
00g

Table 9.10: List of expert group names created within PartBook

Participant	**Score**	**Comment**	**Amendment**
PartBook Liaison	5		
Project Leader	4		
PartBook User	5		

Table 9.11: Interview Results for Requirement 8

9.2.9 Requirement 9

To enable engineers to solicit responses from core competency (expert) groups.

In comparison to task groups, 25 expert groups were created during the eleven week project and were used in 89 communications (18% of the total communications). This shows that expert groups offer the potential for categorising Engineering Design Communications. Looking at the list of 'expert groups', it can be seen that some were erroneous tags but many could be seen as plausible expert groups for the given design project (for example, powertrain, composites and cad).

The results from the interviews discussing the validity of the requirements (Table 9.13) revealed that although the groups were created, the small size of the group meant that the group actually referred to a small group of people. Hence, it may have been the case that the engineers would have 'pushed' it directly to them rather than assign the

Expert Group Names
dynamics
business
powertrain
example
competitor analysis
composites
cad
design manual
oil
(an engineers name)
simulation
fault
sponsorship
combustion
imaginary
maginary @(name
maginary @(name
(an engineers name)
gearbox
trb14idea
ses

Table 9.12: List of expert group names created within PartBook

communication to a specific group. The PartBook Liaison highlighted a limitation of the tool that the experts were not made aware of the communication being added to a group (i.e. no notification).

Thus, it is argued that this requirement has been validated by the study although its implementation within the tool led to issues in the engineers being able to solicit responses by grouping the communication by expert.

Participant	Score	Comment	Amendment
PartBook Liaison	4	Required the expert groups to be looking in the right place	
Project Leader	2	experts were not clearly identified as team is small and hence 3-4 people know answers to all questions	
PartBook User	4		

Table 9.13: Interview Results for Requirement 9

9.2.10 Requirement 10

To enable engineers to assign personal bookmarks to communications

Unfortunately, this was a feature that was not used at all by the engineers, although the interviews on the validity of the requirements does have high scores from the PartBook Liaison and PartBook User, which indicates that it would be important (Table 9.14). The PartBook Leader did indicate that they were not made aware of this functionality and it may be the case that the implementation of task, expert and bookmark tagging used the same method and this may have led to the confusion. Therefore, it is argued that there is insufficient data to assess the validity of this requirement.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	2	was not aware of this	
PartBook User	5		

Table 9.14: Interview Results for Requirement 10

9.2.11 Requirement 11

To define the purpose of the communication (e.g. Table 4.4).

Table 9.1 presents the comparative purpose-response matrix similar to Table 4.6 although this has been generated from the actual purposes and responses within PartBook. 60% of communications used the standard set of purposes, which further corroborates with the feedback provided by the questionnaire highlighting that these require further definition and refinement. This could also be an indicator of the current limit in understanding of Engineering Design Communication.

Sixteen additional purposes were generated by the engineers although most of them were used less than 1% of the time (see, Figure 9.6). By far the most used purpose has been the engineer generated *Discussion* purpose (24%). Feedback from the engineers indicated that they would use this when they were not entirely sure what they wanted from a communication and therefore, not looking for any particular conclusion. *Action Required* was also used relatively often and this was used to deliver tasks to others, which is interesting as it had not originally been intended as a task management tool. An other interesting purpose was *meeting* and informal discussion with engineers revealed that the tool has also been used to manage the agenda and discussion within their internal meetings. Again, showing that users of a tool will also find other uses for it in addition to its original intention.

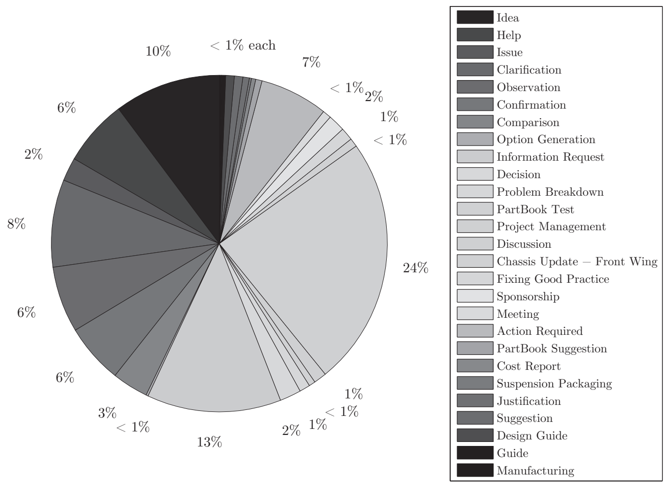


Figure 9.6: Proportions of purposes within the project

Looking at the feedback from the question, *'The purpose tag helped me understand what the engineer wanted from the communication.'*, there is a large spread of opinion on whether it did help the engineers understand the statement made by the engineer creating the communication. Although, there is a negative skew indicating that many found it useful but not for a few. The results from the high-rated/low-rated features of PartBook further show there is a divide on its utility (Figure 9.2). Although, it has been indicated that it may again be useful in terms of future Search & Retrieval (Figure 9.3).

Finally, the interviews assessing the validity of the requirements (Table 9.15) indicate that this is indeed a valid requirement for supporting Engineering Design Communication. They also highlighted the importance of making this mandatory for all communications.

Therefore, these results show that there is a need for a discussion tag, which is for engineers to have communications that do not have a particular purpose. It is also argued that this is a valid requirement for the supporting Engineering Design Communication. Also, future work could investigate how such a tool could be employed to support task management communications as well as engineering meetings.

Participant	**Score**	**Comment**	**Amendment**
PartBook Liaison	5	Compulsory drop downs worked well	
Project Leader	3	drop downs were good intention	
PartBook User	5	Mandatory fields to be filled before creating a post was a good idea	If possible it should be made easier such as a choice determining which of the upcoming mandatory fields needed filling.

Table 9.15: Interview Results for Requirement 11

9.2.12 Requirement 12

To define the type of response for each contribution to the communication

Analysing the responses made by the engineers, 30 additional response types to the original 13 were generated although there were a few that could be classed as repetitions and others generated for the purpose of testing improvements to website. These have been highlighted through superscript numbering in Table 9.1. This leaves a total of 33 different types of response made by the engineers. It is also that case that many response types were re-used across the various purposes of communication. This is an important indicator that there is a set number of response types rather then the seemingly unlimited types of Engineering Record and Foci.

Table 9.16 shows that both the PartBook Liaison and User agreed that this is indeed a valid requirement for supporting Engineering Design Communication. Although, the Project Leader comments on too much information being requested. This comment may not simply refer to this requirements but suggesting there is too much tagging required by the tool. Therefore, future work should consider, which are the most important aspects to capture. Although, from these results, it is argued that this is a valid requirement for supporting Engineering Design Communication.

Participant	Score	Comment	Amendment
PartBook Liaison	5	Compulsory drop downs worked well	
Project Leader	3	A little too much information is requested	
PartBook User	5		

Table 9.16: Interview Results for Requirement 12

9.2.13 Requirement 13

To align the response types to the appropriate purposes.

Looking at the association matrix, it can be seen that it is very sparse. It has been stated previously that is would be foolish to attempt to structure Engineering Design Communication however, the fact that this matrix is not vastly populated and that the engineers had the opportunity to do so may indicate that there is a inherent structure given the purpose of the communication.

Looking at the original set of purposes, 88% of the responses made by engineers used the original response types thereby indicating a relatively high-level of completeness in the responses associated to those purposes. It is also promising to see that some of the original responses were also used by the engineers in their newly generated purposes. Overall, 62% of the responses were of the standard set or derivations thereof. This is encouraging given the limitation of past research not being able to analyse the full extent of responses made by engineers during communications.

The feedback from the students is in a surprising contrast to the quantitative metrics provided above. Figure 9.1 shows the results to the question The initial set of purpose/response & conclusion tags were complete, which indicates that they did not feel it was complete and is a place for future work. It is also the case that the response tags was one of the least favoured features on PartBook (Figure 9.2). Finally, the feedback from the interviews assessing the validity of the requirements (Table 9.16) further highlights its incompleteness and need for clearer definitions between the types of response.

Interpreting these results, it is argued that this is a valid requirement for supporting Engineering Design Communication although more work is required on the definitions and increasing the completeness of the response tags.

Participant	Score	Comment	Amendment
PartBook Liaison	3	It wasn't obvious how this functioned	
Project Leader	2	often wrong or incomplete	
PartBook User	3	needs more clarity	

Table 9.17: Interview Results for Requirement 13

9.2.14 Requirement 14

To ensure an appropriate limit is imposed on the size of a response.

Table 9.18 provides details of the participants assessing requirement thirteen. The scores show that there is no consensus to its validity thus leading to the average being a neutral stance. The comments show that the character limit that was initially set at 255 characters, gave rise to a number of issues and led to the engineer having to reply multiple times in order to get their point across.

This is further indicated by the use of response types such as *Addition* and *Additional Information* as well as feedback provided by the students during the study. Leading to 28% of the communications having the initial engineer replying to their communication in order to provide more information. Therefore, in week five, the character limit was increased to 400 characters although it remained an area of contention. The responses to the statement *the character limit helped focus the discussion on the topic of interest* received the greatest disparity and therefore it is difficult to draw any conclusions. Figure 9.7 shows the responses to the statement '*The character limit should be*', where three options were given: decreased, increased or not exist. It can be seen that the majority favoured increased and therefore, it is argued that a limit should be imposed although further work needs to be done in order to determine an appropriate length.

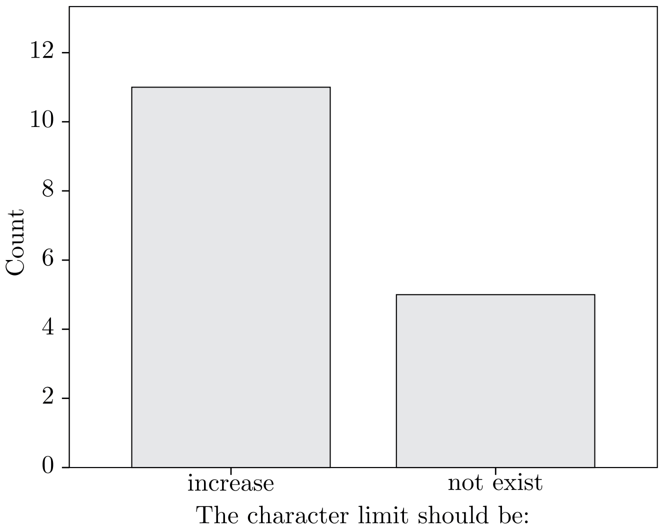


Figure 9.7: Responses to the statement *The character limit should be?*

Thus, it is deemed that this has been partially validated point, however the use of a hard limit may not be an appropriate limitation. Therefore, the requirement should be amended to ensure a method is in place to encourage concise responses.

Participant	Score	Comment	Amendment
PartBook Liaison	4	Hard to mediate. Character length limit became frustrating and making two posts defeated the purpose and just became more work	
Project Leader	2	no limit to replies should be imposed.	
PartBook User	3	character limit needs to be increased. had to create 2 sometimes 3 posts to deliver an analysis result or an idea	

Table 9.18: Interview Results for Requirement 14

9.2.15 Requirement 15

To enable multiple-threads within a single communication episode.

Table 9.19 highlights the validity of this requirement in order to support Engineering Design Communication with a high score. The PartBook user did highlight that the current instantiation of this can be inefficient in terms of space used on the screen. Therefore, a potential amendment would be to provide a consistent method of structuring multi-threaded communications.

Looking at the results from the interviews and its use within PartBook. 62% of communications within PartBook used multiple-threads and was the top rated feature on PartBook. The responses to the statement *the multi-threaded feature helped the team to express different perspectives* received a reasonably high and consistent agreement by all respondents.

Thus, it is argued that this is a valid requirement and a potential refinement would be to enable multiple-threads within a single communication episode that are structured in a consistent manner.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5	excellent	
PartBook User	4	organisation of threads not efficient. sometimes caused overlapping of 2 posts	need to have set positioning if one needs to reply to an existing post. Not drag and drop.

Table 9.19: Interview Results for Requirement 15

9.2.16 Requirement 16

To enable engineers to respond to one or more threads within a communication using a single response.

Unfortunately, the capability to close multiple threads with a single response was not achieved through the functionality provided by the PartBook tool due to time limitations in developing the tool. Therefore, there is insufficient data to assess the validity of this requirement.

9.2.17 Requirement 17

To formally conclude a communication.

Table 9.20 shows the list of conclusion types alongside the associated purpose that have been used in PartBook. The break within the table designates the transition from purposes that were the original set and those that were created during the eleven week study.

Focusing on the original set of purposes, 95% of the conclusions used the original associated conclusion types. This suggests that there is a high-level of completeness, which is promising given that many were logical suggestions due to the lack of research in the conclusion of Engineering Design Communication. Therefore, a key result would be to always provide a positive and negative outcome to the communication.

Also, the additional generated outcomes for the original set of communication types by the engineers were mainly of *action required* or derivation thereof. Informal discussion with the engineers revealed that some communications led to the creation of a task that needed to be completed and therefore used *action required* to highlight this. The relationship between communications and generation of task is an area that could be further investigated.

Reviewing the results from the interviews to assess the validity of the requirement (Table 9.21) received the highest possible score and the engineers felt that it was

Purpose	Conclusion Type
Idea	Good Idea: Pursued (31)
	Good Idea: Did Not Pursue (8)
	Not Plausible (3)
	Already Conceived (5)
Help	Resolved: Process Lesson Learned (24)
	Unresolved: Possible Process Issue (4)
Issue	Resolved: Product Lesson Learned (9)
	Unresolved: Possible Product Issue (1)
Clarification	Clarified (38)
	Not Clarified (3)
Observation	Item of Interest (7)
	Non-Consequential (3)
	Good Work (12)
	Seen Before (2)
	Possible Issue (3)
	Action Still Required (4)
Confirmation	Yes: All Good (26)
	No: Amendments Required (1)
	No Confirmation (1)
Comparison	Option Selected (3)
	No Options Selected (0)
	Hybrid Option (0)
	Organised to Central Location (1)
	All good (8)
	Investigation Required (4)
Option Generation	Options Generated (1)
	Lack of Options (0)
Information Request	Received Useful Information (54)
	Lack of Information (4)
	No Useful Information Received (0)
	Further Action Required (3)
Decision	Decision Made (9)
	No Decision Made (1)
Problem Breakdown	Best Solution (3)
	To be reviewed (2)
PartBook Test	Test Complete (3)
Project Management	Complete (5)
Discussion	To be reviewed (37)
	Agreed (23)
	Good Information (49)
	No Response (3)
Chassis Update - Front Wing	Concluded (4)
Fixing Goo Practice	Conclusion (7)
Sponsorship	Very Good (7)
Meeting	Finished (4)
Action Required	Action Completed (23)
	Further Work Needed (10)
PartBook Suggestion	BLANK (1)
	Agreed (2)
Cost Report	Finished (2)
Suspension Packaging	Negative (1)
Justification	Work in Progress (3)
Suggestion	Noted (3)
Design Guide	All good (4)
Guide	All good (2)
Manufacturing	Good Idea (1)

Table 9.20: Types of Conclusion associated with the various Purposes of Communication

important to capture and understand the actions taken after a communication. However, the PartBook Leader did highlight that it was not possible to to assess whether these following action were ever performed. Therefore, a possible further requirement is for the originating engineer to provide a result of the concluded actions. Thus, based on both the quantitative and qualitative evidence, it is argued that this is a valid requirement and a potential additional requirement is to ensure the engineer provides results from potential actions in the conclusion.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5	this is good to force a response. however conclusions were often 'i will do this to investigate that' and they were never done	
PartBook User	5	straightforward	

Table 9.21: Interview Results for Requirement 17

9.2.18 Requirement 18

To enable engineers to comment on past communications

Considering that the study was of the first eleven weeks of a new design project, it comes as no surprise that only 4% of the communications generated within PartBook contained a HINDSIGHT element. This is not too discouraging as it is acknowledged that this a reference feature primarily aimed at a future project referring back to communication had in a past project. Therefore, it does give an indication that engineers would use this feature but more investigation is required.

The feedback from the interviews assessing the validity of the requirements (Table 9.22) further supports that the students felt this is a valid requirement for supporting Engineering Design Communication. Therefore, it is argued that this has been partially validated due to the lack of use in this study.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5	excellent	
PartBook User	5		

Table 9.22: Interview Results for Requirement 18

9.2.19 Requirement 19

To enable engineers to reference responses in past communications within current communications.

Unfortunately, the feature to reference past communications within new communication was only used seven times throughout the eleven week study. Although, it did feature in the top features of PartBook (Figure 9.2). Feedback from the students revealed that they felt they were too early in the design phase to really use this feature and it was the case that they were using past engineering records as supporting evidence as opposed to their recently generated communications. It seems that they understood the potential of the feature and hence that some believed it to be a top feature of PartBook however a dataset of past communications would be required to investigate this requirement fully.

The feedback from the interviews assessing the validity of the requirements (Table 9.23) further supports that the students felt this is a valid requirement for supporting Engineering Design Communication. Although, the PartBook Leader did highlight the difficulty in usability in the current tool and this would need to be improved. Therefore, it is argued that this requirement has been partially validated as more use cases are required.

Participant	Score	Comment	Amendment
PartBook Liaison	5	Tagging comms numbers worked well	
Project Leader	2	good idea, but hard to find the convos to link to	
PartBook User	5	worked well	

Table 9.23: Interview Results for Requirement 19

9.2.20 Requirement 20

To classify communications by the Company, Product and phase of the Product Lifecycle.

The last requirement was not assessed within this study as the engineers saw the feature as placing too much of a burden on the creation process of the communication. This is because there was no pre-defined structure or process in place in this engineering project and therefore, the engineers would have to define it. Therefore, in order for PartBook to be used, this feature - step four of the creation process - had to be removed.

Figure 9.2 shows that although it wasn't used in this study, the students could see such a classification as potentially useful for search & retrieval purposes. The results from the interviews assessing the validity of the requirements (Table 9.24) did receive positive feedback on the validity of the requirement given a larger engineering project. The PartBook Leader highlights that a simplified version of these categories would have been more suitable for their project. Therefore, it is argued that this is partially validated based on user opinion but a use case is still required. In addition, further work is required on how this classification should be structured for different types of engineering project.

Participant	Score	Comment	Amendment
PartBook Liaison	5	Compulsory dropdowns worked well again	
Project Leader	3	too specific for the top level discussions that we were having. we could have just had powertrain, chassis, business and team organisation to be honest	
PartBook User	4		

Table 9.24: Interview Results for Requirement 20

9.2.21 Summary of Requirements Validations

In summary, 9 requirements were validated, 8 partially validated and 2 had insufficient data to be validated from the results gathered by the analysis of the study. In addition, 4 potential amendments and 1 additional requirements has been elicited. The validation of the requirements has been summarised in Table 9.25.

No.	Requirement	Level of Validity	Amendments
1.	To capture a high quality representation of the originating Engineering Record relating to the communication.	Valid	
2.	To record changes to the Engineering Record as a consequence of the communication.	Partially Validated	
3.	To enable contributing engineers to embed a representation of an artefact in their responses.	Partially Validated	To enable contributing engineers to embed one or more representations of an artefact in their responses.
4.	To provide a text based description of the Engineering Record.	Partially Validated	To provide a semi-automated predictive text-based description of the Engineering Record.
5.	To record/capture the foci of a communication with respect to the Engineering Record	Partially Validated	To highlight the specific area upon the representation relates to the foci of the communication.
6.	To provide an electronic or physical reference to the Engineering Record.	Valid	
7.	To enable engineers to 'push' communications to one another.	Valid	
8.	To enable engineers to group communications by task.	Partially Validated	
9.	To enable engineers to solicit responses from core competency (expert) groups.	Valid	
10.	To enable engineers to assign personal bookmarks to communications.	Insufficient Data	
11.	To define the purpose of the communication (e.g. Table 4.4).	Valid	
12.	To define the type of response for each contribution to the communication (e.g. Table 4.5).	Valid	
13.	To align the response types to the appropriate purposes (Figure 4.6).	Valid	
14.	To ensure an appropriate limit is imposed on the size of a response.	Valid	
15.	To enable multiple-threads within a single communication episode.	Valid	To enable a structured multi-threaded experience within a single communication episode
16.	To enable engineers to respond to one or more threads within a communication using a single response.	Insufficient Data	
17.	To formally conclude a communication (e.g. Table 4.7).	Valid	
18.	To enable engineers to reference responses in past communications within current communications.	Partially Valid	
19.	To enable engineers to comment on past communications (e.g. Table 4.8).	Partially Validated	
20.	To classify communications by the Company, Product and phase of the Product Lifecycle.	Partially Validated	
	Additional Requirements		
	to ensure the engineer provides results from potential actions in the conclusion		

Table 9.25: The Validity of the Requirements

9.3 Validating the Considerations

Continuing on from the validation of the requirements for supporting Engineering Design Communication, this section provides the results and discussion on the validity of the considerations when taking a Social Media approach.

9.3.1 Consideration 1

That users can present their expertise and differentiate themselves from one another

Table 9.26 reveals that the participants feel that being able to present their expertise and differentiate themselves from one another is a valid consideration. The comments made by the participants indicate that this - typically referred to as 'profile' information - should be collected upon signing up to the tool. Although it was not mandatory to fill in the profile information on PartBook, 76% of the engineers did complete their respective profiles further indicating the need to consider this aspect when creating a Social Media Approach. Therefore, it is argued that this is a valid consideration when taking a Social Media Approach.

Participant	Score	Comment	Amendment
PartBook Liaison	4	Mandatory profile could be used before the first post to collect the info	
Project Leader	5	most of these are pointing to a facebook app of partbook. this would be excellent	
PartBook User	4	profiles need improvement in terms of the information that can be put	Mandatory fields could help

Table 9.26: Interview Results for Consideration 1

9.3.2 Consideration 2

That users can associate themselves with others

The engineers were able to associate themselves with one another through unstructured tagging based on task and expert groups. As mentioned previously in requirements 8 & 9, 6 task groups were created with one communication in, and 25 expert groups were created which were used in 18% of the communications. Table 9.27 shows that two of the respondents assessing the validity of the requirements were unsure on its validity. The PartBook Liaison highlighted that it 'wasn't how you could do this' and a potential reason for this comment is that the tool did not present who was 'interested' in which group. Thus, it is argued that a usability issue prevented the engineers to understand how they were associated with one another. Therefore, it is deemed that insufficient data has been provided by this study in order to validate this consideration.

Participant	Score	Comment	Amendment
PartBook Liaison	3	Wasn't clear how you could do this	
Project Leader	5		
PartBook User	3		

Table 9.27: Interview Results for Consideration 2

9.3.3 Consideration 3

That users can access all the content stored within the system (where possible)

Table 9.28 shows that the participants of the validation interviews feel that all the content stored within a Social Media system should be made accessible by all where possible. This was indeed the case for PartBook and the answers to the question *I took part in communications that I would otherwise not have known about* received a consistent positive feedback with very little skew (Figure 9.1). This could be seen as an indicator that enabling access to all communications enables knowledge sharing between engineers where previously it would not have been possible. Therefore, it is argued that this is a valid consideration when taking a Social Media Approach.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5		
PartBook User	5		

Table 9.28: Interview Results for Consideration 3

9.3.4 Consideration 4

That all the relationships between the users, content and communications are formed

Consideration four also received the highest rating possible in the interviews (Table 9.30). The lack of comments may also suggest that they felt all the potential relationships have been considered within the PartBook tool and a summary of the types of relationship formed is shown in Table 9.29. These have already been discussed with respect to their requirements. Therefore, based on these results, it is argued that this is a valid consideration and that it has also been met by this Social Media Approach to support Engineering Design Communication.

Relationship	Sum
Person-to-Person	571
Engineering Record Reference	154
Task Groups	6
Expert Groups	25
Bookmarks	0

Table 9.29: Relationship formed within PartBook

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5		
PartBook User	5		

Table 9.30: Interview Results for Consideration 4

9.3.5 Consideration 5

That users can access the Social Media tool, independent of which device they choose to use

The results from the feedback assessing the validity of the considerations can be seen to be skewed by the issues found using the PartBook tool (Table 9.31). Although, the PartBook User has requested a smartphone app to improve the experience. This consideration is further supported by Figure 9.8, which demonstrates that many platforms were used to access and interact with the tool. The need for mobile support can be seen as a necessity as the engineers used the tool even though the site had not been fully optimised for those devices. Therefore, it is argued that this consideration has been partially validated as the use case evidence shows that the engineers are using an array of platforms however, the feedback from the engineers did not focus on the consideration but rather, the usability issues of the tool.

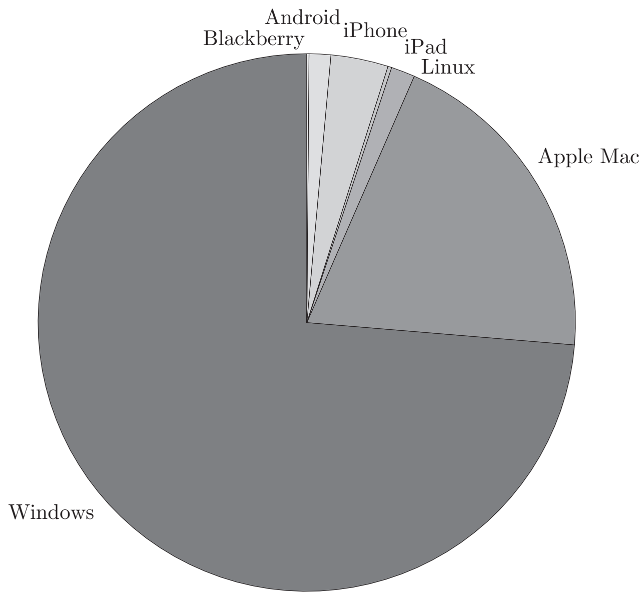


Figure 9.8: Platforms used by the engineers accessing PartBook

Participant	Score	Comment	Amendment
PartBook Liaison	3	Some issues with certain browsers and logging on, use from mobiles would be great	
Project Leader	5		
PartBook User	3	problems with logging on. had to clear cache several times	smartphone app

Table 9.31: Interview Results for Consideration 5

9.3.6 Consideration 6

That core meta-data such as author, creation and location are captured

Table 9.32 shows that the participants felt that this is an important consideration when developing a Social Media Approach. This was also achieved within PartBook as all content generated also automatically recorded these details. Apart from achieving this within the tool, it is argued that this has been partially validated and it would be interesting to understand the effect of not capturing this data on the utility of the tool.

Participant	**Score**	**Comment**	**Amendment**
PartBook Liaison	5		
Project Leader	4		
PartBook User	5	clear	

Table 9.32: Interview Results for Consideration 6

9.3.7 Consideration 7

That structured tagging is used where there is a requirement for content to have such meta-data

Structured tags have been used throughout the tool to capture necessary meta-data pertaining to Engineering Design Communications. These have been the purpose, response, conclusion and hindsight types alongside the type of engineering record and particular focus upon that record. Figure 9.9 shows the counts of the various structured tags at the end of the eleven week period indicating that they have been used throughout the tool. The relevance of which, has been discussed in the respective requirements. The feedback from the participants considering the validity (Table 9.26) show a slight agreement that this is indeed a valid consideration for developing Social Media tools. Referring back to the potential perspectives for Search & Retrieval (Figure 9.3) reveals that many of these structured tags would

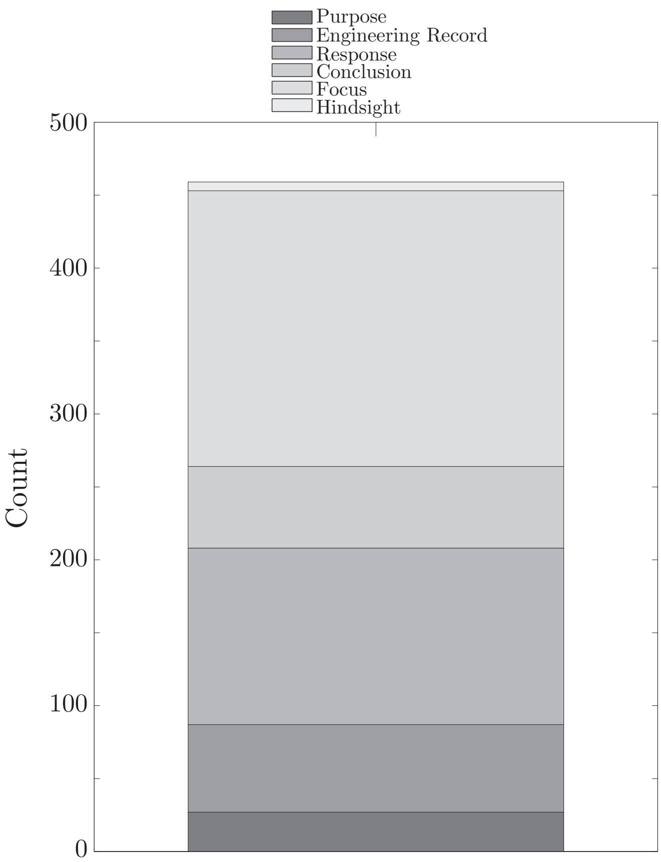


Figure 9.9: Number of structured tags generated within PartBook

be re-used and therefore necessitating them for every communication would mean that all communications could be retrieved using these dimensions. Therefore, it is argued that this is a partially valid consideration as it has been used extensively within PartBook although the feedback provided by the engineers does not provide enough evidence for full validation.

Participant	Score	Comment	Amendment
PartBook Liaison	3		
Project Leader	5		
PartBook User	4		

Table 9.33: Interview Results for Consideration 7

9.3.8 Consideration 8

That unstructured tagging is used to provide an opportunity for additional relationships to be formed

The unstructured tagging was implemented for the grouping of communications, alerting other engineers to a communication and to refer back to previous communications. Each had varying levels of success that has been discussed within the validation of their respective requirements (See requirements 7, 8, 9, 10 & 19). It may be the case that the same functionality present in PartBook was used to generate these tags and this may have led to confusion between whether they were generating a link to a person, expert group, task group or personal bookmark. Table 9.34 reveals that two of the three participants were in agreement that this was a valid consideration. The PartBook Liaison makes the point that understanding how the tagging works within a tool is important for it to be used effectively. Therefore, it is considered that using unstructured tagging is used to enable additional relationships to be formed has been partially validated. However, a potential amendment could be that the functionality of unstructured tagging should be clearly defined and different for each type of unstructured tag one wishes to use.

Participant	Score	Comment	Amendment
PartBook Liaison	5	A demo of how to tag would have been useful but once it was understood how the tagging system worked it went well	
Project Leader	3		
PartBook User	5		

Table 9.34: Interview Results for Consideration 8

9.3.9 Consideration 9

That character limitation is used in situations where focus upon the communication needs to be maintained

This consideration is closely related to the results used to assess the validity of requirement 14, which did indicate that a method to limit the character length should be imposed although a better method could be developed. This is further shown in the respondents' comments in Table 9.35 that highlights that the engineers used work-arounds to continue their statement beyond the character limit. In fact, this occurred in 28% of the communications within PartBook. Therefore, it is deemed that this consideration is partially valid as user opinion in requirement 14 revealed that a method should be in place but the use case method was not too restrictive.

Participant	Score	Comment	Amendment
PartBook Liaison	4	As above, multiple posts could be used to get around this	
Project Leader	3		
PartBook User	3	people ended up creating multiple posts.	

Table 9.35: Interview Results for Consideration 9

9.3.10 Consideration 10

The provision of a notification system within a Social Media tool for user activity and to ensure users are able determine their notification preferences

During the eleven week period, a total of 4,879 notifications were sent from the tool. Figure 9.10 presents a histogram of the typical number of notifications an engineer received per day. It comes as no surprise that the feedback from the participants considered the notification that was employed to be a nuisance (See comments in Table 9.36). However, the comments all suggest that the system needs to be improved and not removed entirely which may confirm that it is a valid consideration when taking a Social Media Approach. Thus, although the system employed was not seen as the best solution, it is argued that this is indeed a valid consideration when taking a Social Media Approach.

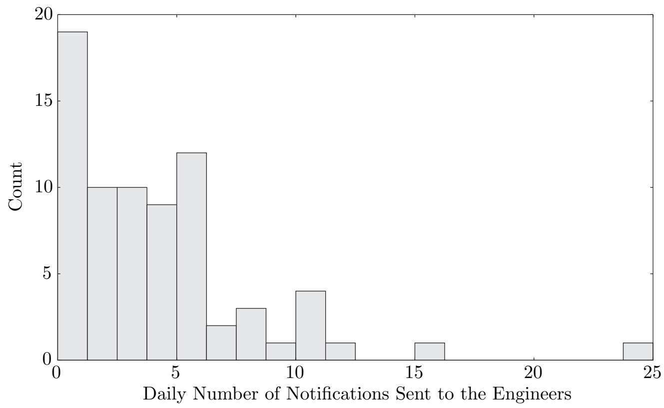


Figure 9.10: Histogram of Notifications Sent Per Day (Average Per Person)

Participant	Score	Comment	Amendment
PartBook Liaison	2	A more concise system that notified the appropriate users would have been better	
Project Leader	5		
PartBook User	3	a better system is needed	notification via email needs to be disabled

Table 9.36: Interview Results for Consideration 10

9.3.11 Consideration 11

How to take advantage of the fact that 'richer media' can aid browsing and the definition of the topic of communication

The answers from the statement '*the images aided my understanding of the communication*' has a comparatively positive result as well as a positive skew showing that they were useful to many and especially to some. Finally, the feedback from the open-ended statement '*Please explain how/how not the use of images was useful to you*' contained an interesting point, which showed that a few of the respondents found the representation proved incredibly useful in terms of search & retrieval of communications rather than scanning through the various statements.

> "It is far more natural/easier to remember the image associated with a particular communication than remembering the text based title."
>
> Respondent 7

Referring to Table 9.37, it can be seen that the participants of the validity interviews considered this a valid consideration with respect to a Social Media Approach. Therefore, it is argued that this is a valid consideration.

Participant	Score	Comment	Amendment
PartBook Liaison	5		
Project Leader	5		
PartBook User	4		

Table 9.37: Interview Results for Consideration 11

9.3.12 Summary of Consideration Validation

In summary, six considerations were deemed valid, four were deemed partially valid and one had insufficient data. In addition, one amendment has been generated. Table 9.38 provides a summary of this validation.

No.	Consideration	Level of Validity	Additional Notes
1	that users can present their expertise and differentiate themselves from one another.	Valid	
2	that users can associate themselves with others.	Insufficient Data	
3	that users can access all the content stored within the system (where possible).	Valid	
4	that all the relationships between the users, content and communications are formed.	Valid	
5	that users can access the Social Media tool independent of which device they choose to use.	Partially Valid	
6	that core meta-data such as author, creation and location are captured.	Partially Validated	
7	that structured tagging is used where there is a requirement for content to have such meta data.	Partially Validated	
8	that unstructured tagging is used to provide an opportunity for additional relationships to be formed.	Valid	The functionality of unstructured tagging should be clearly defined and different for each type of unstructured tag one wishes to use.
9	that character limitation is used in situations where focus upon the communication needs to be maintained.	Partially Valid	
10	the provision of a notification system within a Social Media tool for user activity and to ensure users are able determine their notification preferences.	Valid	
11	how to take advantage of the fact that 'richer media' can aid browsing and the definition of the topic of communication.	Valid	
	Additional Considerations		

Table 9.38: The Validity of the Considerations

9.4 Chapter Summary

This chapter has sought to validate the requirements and considerations upon which the Social Media Framework has been designed. Various qualitative and quantitative information sources were used in the validation, which has led to 14 valid requirements/considerations, 11 partially validated requirements/considerations, and 2 requirements/ considerations that had insufficient data to assess their validity. In addition, 5 amendments were made and 1 potential new requirement has been generated. Tables 9.25 and 9.38 provide a summary of the validation status of the requirements and considerations respectively.

Chapter 10

Evaluating the Social Media Approach

This chapter presents the results from the evaluation of the Social Media Approach. Evaluation is where one looks to determine the impact of the implementation of a tool/process/method (i.e. PartBook) within the context of an engineering project. In order to achieve this, an exploratory analysis of the dataset has been performed to investigate the potential impact that the tool has/could have on Engineering Work, Engineering Records and Engineering Project Management. Each is discussed in its respective section.

10.1 Engineering Work

Figure 10.1 shows the impact on the instances of communication between E-Mail and PartBook during the eleven week study. Clearly, E-Mail was used substantially in the first few weeks but as the project progressed, the use of PartBook increased and E-Mail decreased. As the total level of communication does not vary greatly over the weeks, it is argued that the Engineering Design Communications that would have been held within E-Mail are actually occurring within PartBook. Thus, there is a transference of communications to the new tool and as the total instances of communication across the weeks is fairly consistent, it provides some evidence to suggest that the addition of new tools does not necessarily increase the workload of the engineers in terms of the total number of communications

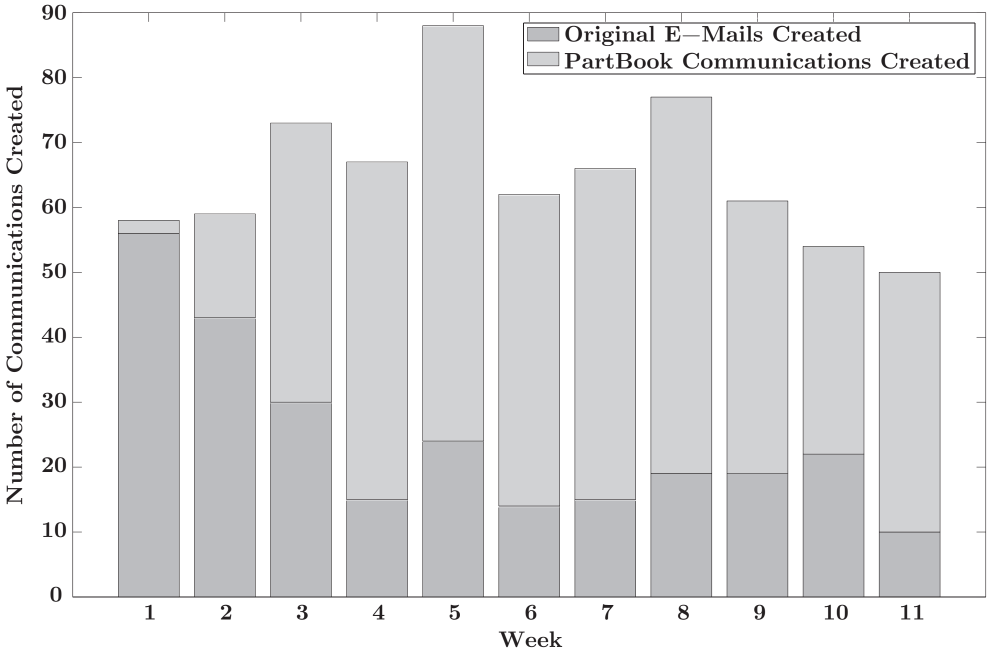


Figure 10.1: The Volume of Communication through both E-Mail and PartBook

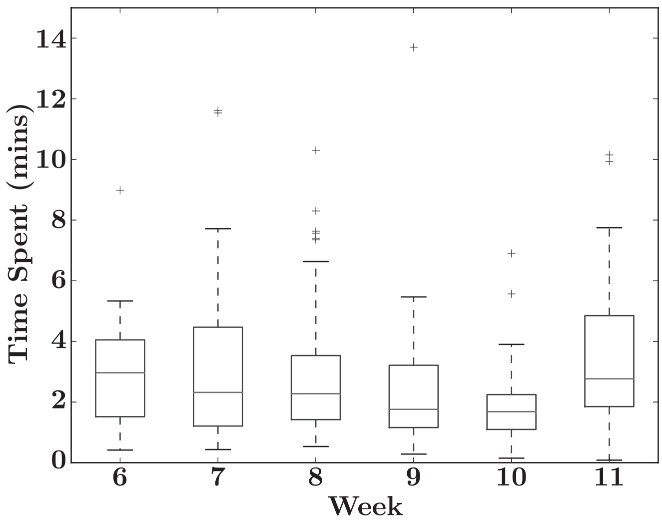
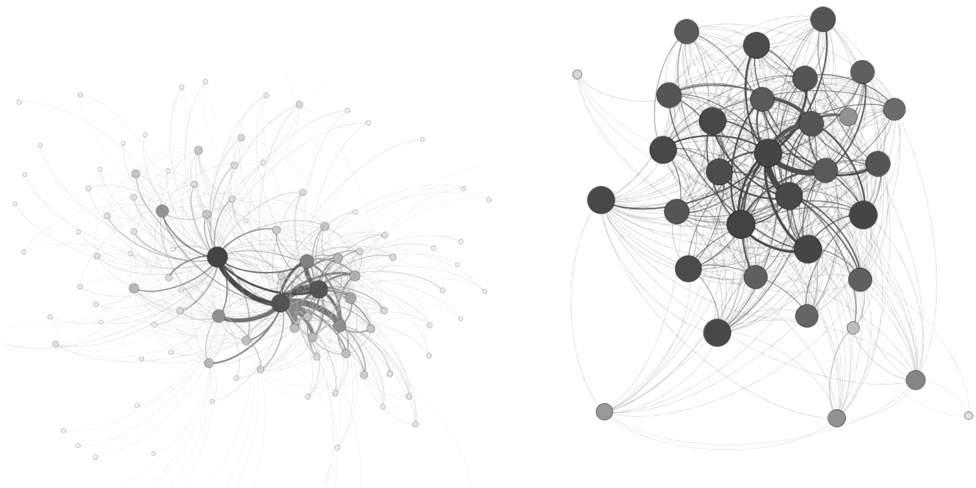


Figure 10.2: Time taken to generate a communication within PartBook

To understand the impact upon an engineers' work further, Figure 10.2 shows the distribution of the time taken to generate a communication within PartBook over the eleven weeks. This time was calculated from the time an engineer opened the new communication page to the time it takes it to be submitted. The box plots are fairly consistent over the eleven weeks with the majority of the communications taking between 2-4 minutes. This consistency suggests that the engineers became instantly familiar with the generation of a communication within the tool. Although, there were a few outliers that see some engineers taking more than 10 minutes. Feedback from the team suggested that these were cases when an individual would start the 'creating communication process' before having the image of the record available to them. Thus, this extra time was where they were creating that image to upload to the tool. Even though, the fact remains that it took a relatively short time to create the communications within PartBook especially when one considers that the average length of an original E-Mail (i.e not a reply or forward) for the team consisted of 118 words on average and with a typical speed of 19 words per minute for composition, this leads to an average creation time for an e-mail to be predicted



(a) E-Mail (b) PartBook

Figure 10.3: Communication networks produced by E-Mail and PartBook

as approximate six minutes [Karat et al., 1999].

The final aspect that has be considered with respect to Engineering Work is the effect of the tool on the collaborative nature of the engineers. Figure 10.3 provides a visual depiction of the communication network generated by both tools. Each node is representative of an engineer with the size determined by the number of connections to that node (degree). It can be seen that E-Mail appears to have a few highly connected engineers, whilst the level of connectedness is more evenly distributed in the PartBook. This is further shown by the average degree values of 8 and 23 respectively. Although, it has to be noted that E-Mail was the method used to communicate with people outside of the engineering team and that does influence the result as they would not be connected to all the engineers within the team. Even though, the magnitude of difference between the two levels of degree does highlight the potential for Social Media based tools to provide a more collaborative method of communication.

10.2 Engineering Records

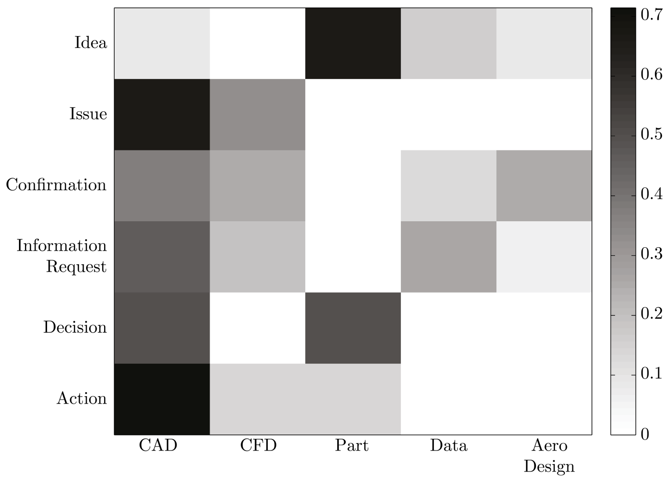


Figure 10.4: The relationships between the purpose of a communication and record it pertains to.

As mentioned throughout this work, communications are closely related to the engineering record being generated by the engineer. This can be confirmed by Figure 10.4, which presents a matrix of the ratio of various purposes of communication with respect to the Engineering Record that it pertains to. It can be seen that within this project, most of the issues and actions were primarily surrounding CAD files and many ideas and decisions were related to the physical parts of the product. This appears to be a logical result as the team had last years' car to take apart and analyse, therefore many of their ideas could be seen as potential improvements from last years model. This may be a potential indicator of the level of re-design being undertaken from a previous product. In respect to having a high number of issues and actions relating to CAD parts, this could be due to the fact that one of the key outputs of the project is to have a digital mock-up of the car. It is logical to assume that the engineers would potentially be focusing on this aspect even more so than other areas of the project hence the greater number of issue and actions being generated. This could be potentially useful in identifying key areas of focus during the evolution of an Engineering Project. Confirmation can be seen throughout all the record types apart from part, this may be due to the fact that parts are more likely to be related to parts from the previous car and thus not objects generated by themselves and leads us to the potential that confirmation is used by engineers for their own work and records they generate.

Figure 10.5 shows how the generation of communications related to their record type changed over time. It can be seen that many discussions at the initial stage were related to parts and as discussed above, this seems a logical result as the engineers may be discussing last years' car and how they might improve upon it. CFD communication has a steady accumulation over time, which could may be an indicator for a steady level of work being performed within that area. This is in stark contrast to records termed 'aero design', which appears much later in the process. As the engineers that are partaking in the project have had little or no experience of CFD or fluid dynamics, this trace potentially demonstrates a learning curve where the engineers are getting familiar with the tool before presenting any concepts of the car design in relation to its aero performance. Looking at the CAD communications, it appears that there is a slight increase in the rate of communication as the project progresses. This may indicate the increasing importance of the CAD work with respect to the other record types. Although not conclusive, this graph provides some indications that communication related to its record type has the potential to give insights into the state of a project.

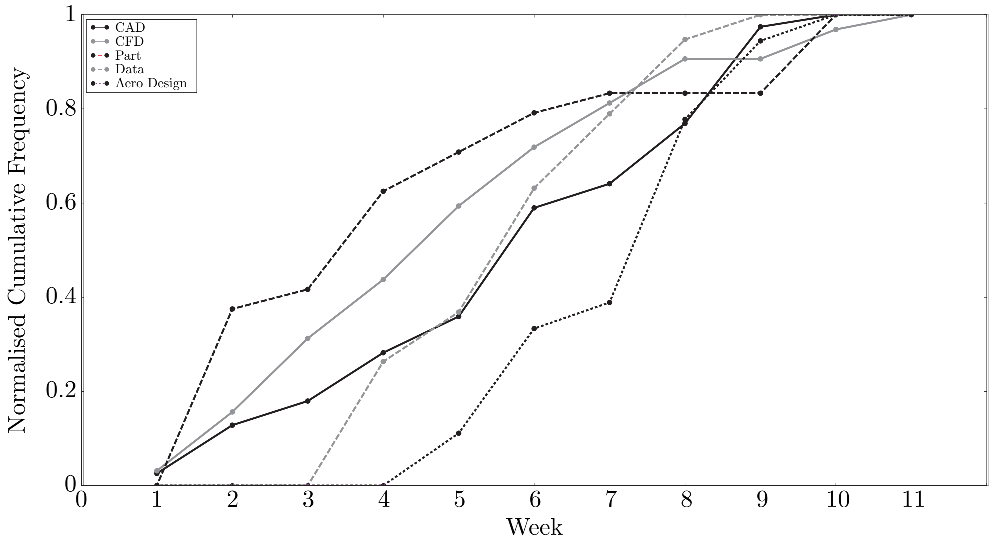


Figure 10.5: The normalised cumulative frequency of communication relating to the various types of Engineering Record

10.3 Engineering Project Management

Figure 10.6 provides an insight into the typical length in terms of number of replies for the various purposes of communications used within PartBook as well as showing the average number of people involved in these communications. The box plots show that there are distinct differences in the distributions between the various purposes of communication. For example, *idea* shows a high number of responses whilst *action* contains very little. *Decision* and *confirmation* both have the majority of the communications with a low number of replies but also have a positive skew showing that there are a minority of responses in the region of 10-15. This may be of interest to Engineering Project Management as it may indicate levels of agreement upon particular subjects and possible areas of uncertainty. 80% of the purposes had an average number of participants being greater then two, indicating the collaborative nature of Engineering Design Communications.

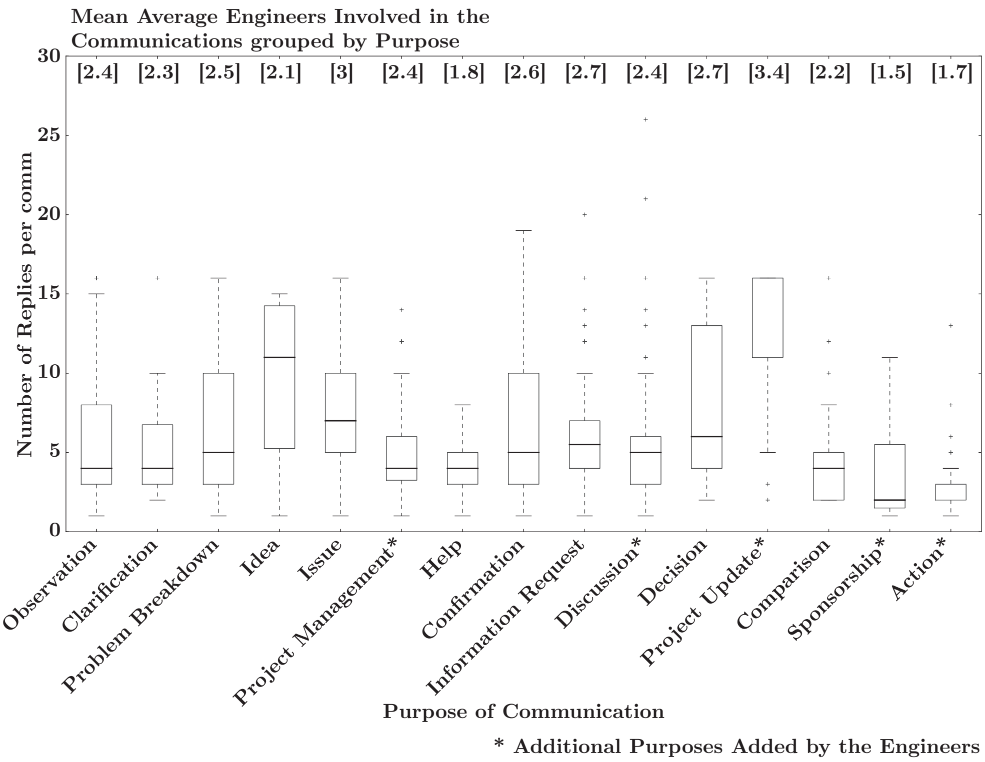


Figure 10.6: The number of replies and the average number of engineers involved in the various communication types

Figure 10.7 shows changes in the instances of various purposes of communication across the duration of the study. Firstly, differences can be seen between the various purposes of communication and that some appear to coincide with events in the project schedule. Thus, it presents the opportunity for patterns to be identified that could be of potential use to Engineering Project Management in understanding how the project is developing and further confirms past research showing that this may be the case [Wasiak, 2010]. There is a high-level of idea generation at the conceptual design phase and the number of instances drop considerably as the project reaches the design freeze milestone. This potentially shows the convergence of a solution. Noting that there is likely association between the two features, if one were to have a number of these events, it may be possible to associate the outcome of the design freeze to the pattern in idea generation. Therefore, the shape of the instances of idea generation before the design freeze meeting could provide a useful indicator to the likely outcome. Engineering Project Management could use such information to provide intervention if and when required. One example may be altering the dates of review meetings to better coincide with the completion of work.

Two peaks can be seen in the instances of information request and both occur early on in each phase. A potential explanation for this is that at the beginning of the conceptual design phase, the engineers firstly seek to understand the problem that they face and then seek information in an attempt to solve it. This can be also said for the detailed design phase although the problem is now greatly constrained. It is also unsurprising to see that decisions rise in conjunction with the arrival of the design freeze although it is confirmation that rises with the technical report hand-in. It is argued that this is because the technical report hand-in is part of the individual assessment of the engineers and therefore confirmation is the most suited purpose of communication as the project leaders wish to ensure that everyone is ready to hand them in.

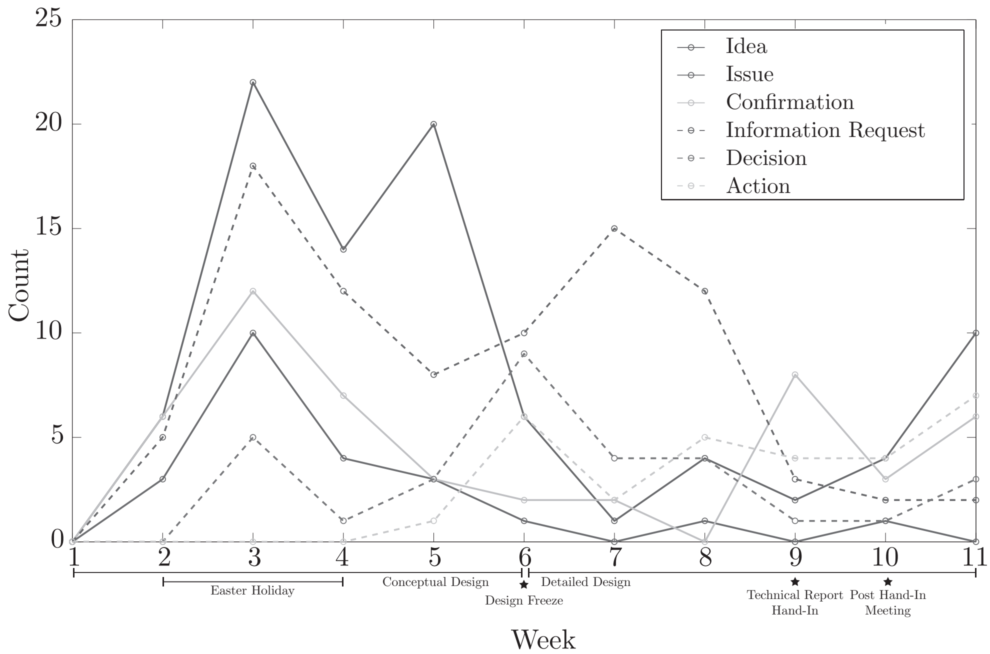


Figure 10.7: The instances of various purposes of communication across the duration of the study

Figures 10.8 & 10.9 show the potential for differentiating engineers within an engineering project based upon their communications in relation to purpose, response types and against the engineering record that the communication is related to. Looking at Figure 10.8, it can be seen that both engineer 1 & 2 generate the most Information Request whilst engineers 3 & 4 start the most discussions. Then there is engineers 2, 3 & 4 who have presented the most number of ideas. It is difficult to draw any conclusions from this directly, although it is argued that this may relate to the role, personality, expertise and/or capability of the engineers involved. The key point is that one engineer can be differentiated from another based on this dimension. This can also be said for the types of reply an engineer typically makes where engineer 9 can be seen to make many opinion based statements independent of the purpose the communication whilst engineer 1 makes opinion statements to information requests and discussion statements in discussion communications rather than opinion statements.

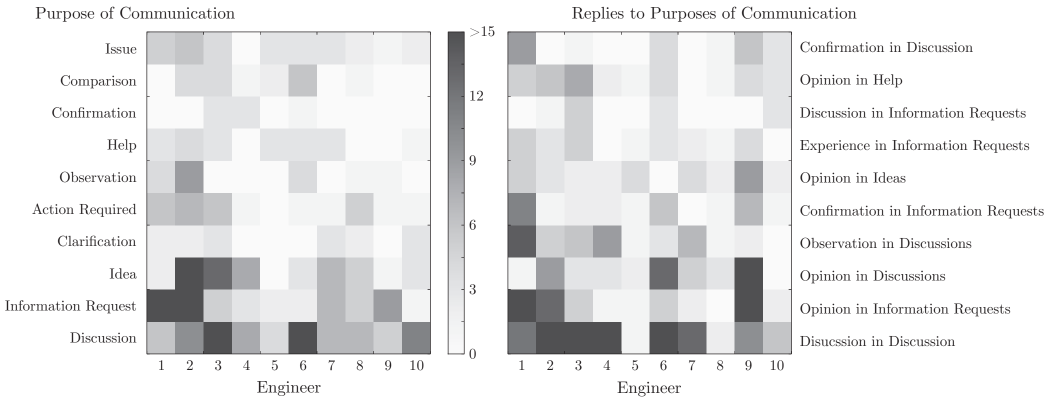


Figure 10.8: Identifying knowledgeable engineers through the purposes of communication and their response types.

Figure 10.9 provides a bipartite graph that relates the engineers to the engineering records with the weighted edges representing the number of communications with respect to the engineer and record. Again, the size of the node is dependent of the degree of that node. The figure clearly demonstrates that there are key members for each type of engineering record. Engineer 20 is highly associated with CAD, for example. This is the same for engineer 10 and Sponsorship. Engineer 11 is highly-related to both CFD and Aero Design. Such a view on the engineering project has the potential to highlight the knowledgeable/key influential engineers on the various facets of the project. It can also distinguish potential integrators or engineers with a wider breadth of knowledge such as engineer 24 & 13. Such information could be used to automatically assess engineers skill sets, enable appropriate Engineering Work to be sent to the *right* engineers and as a monitor of collaboration activities between various departments.

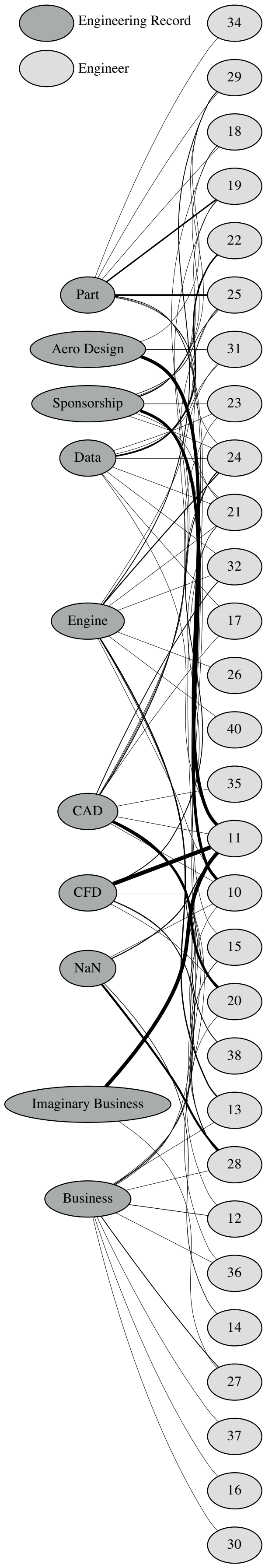


Figure 10.9: Identifying knowledgeable engineers through the Engineering Records.

10.4 Chapter Summary

This chapter has evaluated the Social Media Approach through understanding the impact the tool has had with respect to Engineering Work, Records and Project Management. From this, one can begin to understand how Social Media could support Engineering Design Communication. It has been interesting to see that despite having an additional tools for communication, the general volume of communication was hardly affected. The time taken to generate communications was also seen to be consistent throughout the project suggesting almost instant familiarity with the tool. It has even been suggested that the PartBook tool is an quicker method of generating Engineering Design Communications when compared to E-Mails.

The information captured by the tool has provided some interesting insights into how the purpose of a communication can be strongly related to the type of engineering record to which it pertains. In addition, differences in the rate of communication generation pertaining to the various records throughout the project has been demonstrated and this may have potential implications if one where trying to assess the state of a project such as phase and current priorities.

Finally, the tool has the potential to indicate the level of collaboration between engineers within a project as well as determining bounds of normality for certain purposes of communication. Differences in any of these attained levels in real-time could aid the reaction time of Project Management to project events. It has also been that case that different purposes of communication vary considerably throughout the project and may indicate the real-time status of the project which could then be compared to the planned project status, thus enabling Project Managers to better ascertain the action required to progress the project further.

Chapter 11

Discussion & Conclusion

This thesis has described the importance of Engineering Design Communication as the main tributary for the sharing of knowledge, thoughts and ideas pertaining to the product. Discussion of the extant literature highlights that the current methods for distributed communication - primarily E-Mail - do not provide the specific support necessary for Engineering Design Communication. A number of challenges in supporting Engineering Design Communication were discussed in the introduction and summarised by Al-Rawas and Easterbrook [1996] as:

1. *The Ineffectiveness of the Current Communication Tools* to support distributed Engineering Design Communication due to inability to capture the engineering context.
2. *The Restrictions on Expression within Communication Tools* and particularly in enabling engineers to collaborate in a more natural way.
3. *The Social and Organisational Challenges,* which include ensuring there is awareness of the communication to enable the right engineers to contribute and ensure the right dimensions are captured alongside the communication to enable easy search and retrieval.

Further, it has been identified that little prescriptive research has been performed to improve this situation. However, with the advent of Social Media and associated technologies that better support communication within a given community, it was contended that a Social Media approach could overcome these challenges. In addition, Engineering Design Communication has key significance in relating rationale and understanding behind Engineering Work, Records and Project Management. The potential in capturing these relationships with respect to how it could lead to further understanding of a project's status and progression has also been discussed. This led to the aim of the thesis:

Aim

To investigate how Social Media can be used to support Engineering Design Communication.

To further understand the context of this research, a literature review focusing upon the terms Engineering Design, Engineering Context, Engineering Work, Engineering Records and Engineering Project Management ensued (Chapter 2). Each were defined alongside the relationship communication has with them.

Engineering Design was defined as all the aspects that are required in order to generate and develop a product, and is "*fundamentally socio-technical*" where communication is essential. Engineering Design is performed within the wider Engineering Context, which considers the external factors that are placing further challenges on the engineers. These are the need to consider - to an even greater extent - the impact of the product across its entire life cycle, and the need to support the search, retrieval and re-use of past records in an ever-expanding and varied set. This is occurring within an environment that is becoming ever-more distributed and mobile. Leading to the greater use of distributed communication tools that do not currently provide the support required for Engineering Design Communication.

Communication also features heavily in Engineering Work, which pertains to the actual activities performed by the engineers. It provides a crucial role by enabling engineers to share information & knowledge, maintain awareness of project progress and deliver the key outcomes of their activities. In addition, communication plays an important role in Engineering Records, which covers the data, information and knowledgeable information that is captured and stored across the Product Lifecycle. This is because it is a container for the rationale of a records' evolution and how it is re-used. Finally, Engineering Project Management was defined as the organisation, co-ordination of engineering teams as well as monitoring the progression and status of a project. It was discussed that monitoring the instances of communication alongside the analysis of the content of communication has the potential to aid Engineering Project Management.

This review further supported the need for such research to be conducted as well as identifying the need for research in this area to validate its underlying theory and evaluate its potential impact within its context.

Chapter 3 then considered the Research Methodology. In order to meet the aim, the research applied the Design Research Methodology (DRM) in conjunction with a flexible research strategy due to the considerations that need to be taken when researching the 'real-world' (Figure 11.1). In doing so, the aim was broken down into three Research Questions that aligned with the DRM framework (Table 11.1).

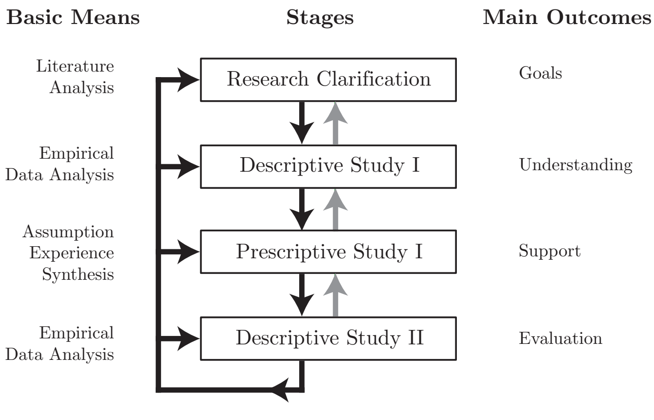


Figure 11.1: DRM Framework (*From*: Blessing and Chakrabarti [2009, p.15], *Re-Illustrated*)

DRM Stage	Research Question
Descriptive I	RQ-1: What are the requirements for supporting Engineering Design Communication?
Prescriptive I	RQ-2: How can Social Media be used to support Engineering Design Communication?
Descriptive II	RQ-3: How does Social Media support Engineering Design Communication?

Table 11.1: The alignment of the Research Questions to the DRM Framework

The following sections discuss in detail how each research question has been addressed and how the overall aim has been met.

11.1 Research Question One

In order to determine the requirements for supporting Engineering Design Communication, an in-depth review of the literature relating to Engineering Design Communication, which covered approximately 100 papers was conducted (Chapter 4). The review was arranged into four areas relating to Engineering Design Communication; Engineering Records, Engineers Work, Its Purpose and Evolution and the Engineering Context. Throughout this review, the requirements for supporting Engineering Design Communication were elicited and synthesised. The final set of requirements numbered 20 and are summarised in Table 11.2. At this point, the requirements had yet to be validated.

Requirement No.	**Requirement:**
1	To capture a high quality representation of the originating Engineering Record relating to the communication.
2	To record changes to the Engineering Record as a consequence of the communication.
3	To enable contributing engineers to embed a representation of an artefact in their responses.
4	To provide a text based description of the Engineering Record (Table 4.3).
5	To record/capture the foci of a communication with respect to the Engineering Record (Table 4.3).
6	To provide an electronic or physical reference to the Engineering Record.
7	To enable engineers to 'push' communications to one another.
8	To enable engineers to group communications by task.
9	To enable engineers to solicit responses from core competency (expert) groups.
10	To enable engineers to assign personal bookmarks to communications.
11	To define the purpose of the communication (e.g. Table 4.4).
12	To define the type of response for each contribution to the communication (e.g. Table 4.5).
13	To align the response types to the appropriate purposes (Figure 4.6).
14	To ensure an appropriate limit is imposed on the size of a response.
15	To enable multiple-threads within a single communication episode.
16	To enable engineers to respond to one or more threads within a communication using a single response.
17	To formally conclude a communication (e.g. Table 4.7).
18	To enable engineers to reference responses in past communications within current communications.
19	To enable engineers to comment on past communications (e.g. Table 4.8).
20	To classify communications by the Company, Product and phase of the Product Lifecycle.

Table 11.2: Summary of the Requirements Elicited from EDC Literature

Ahead of the full validation of the requirements, an initial study into the current communication practices of a Small-to-Medium Enterprise was conducted (7.3). This was performed as a check against the review of the literature. The results did support past findings by:

- Highlighting the significant use of computer-mediated communication (i.e. E-Mail) (See Figure 7.13)
- Identifying that engineers typically send communications of a singular purpose (see Figure 7.14).
- Demonstrating a level of completeness with respect to the various purposes an engineer would wish to communicate (see Figure 7.15).

The full validation of these requirements appears in Chapter 9 through the analysis of the dataset generated from the Formula Student project using the PartBook tool. As was highlighted in the Research Methodology, the study was one of the 'real-world' and the implication was to ensure a rigorous data collection strategy involving multiple methods (see Table 3.3). Thus, the validation of the requirements used interviews aimed specifically to ascertain the validity of the requirements, a questionnaire to gather feedback on PartBooks' functionality and the captured PartBook communications.

The validation of the requirements concluded that 9 requirements were validated, 8 partially validated and 2 had insufficient data to be validated from the results gathered. In addition, 4 potential amendments and 1 additional requirement were established (see Table 9.25). In addition, four key insights from the analysis are highlighted:

1. The positive feedback for having the ability to have multi-threaded communications (see Section 9.2.15).
2. The significant use of images to aid understanding of the statements being made despite the usability issues present within the tool (see Section 9.2.3).
3. The importance of enabling engineers to use their own engineering social knowledge to identify the *right* engineers for a communication (see Section 9.2.7).
4. The relative completeness of the tags used to describe the evolution of the communication (i.e. Purpose, Response and Conclusion Tags) (see Sections 9.2.11-13,17).

This analysis concludes the work performed on answering Research Question One and has led to a validated set of requirements for supporting Engineering Design Communication.

11.2 Research Question Two

In order to answer Research Question Two, Chapter 5 generated a set of considerations for developing a Social Media Approach. This has been achieved through a literature review, which provides an understanding of the concept of Social Media alongside the current best practice in applying Information Technology to achieve this. The review elicited eleven considerations, which are summarised in Table 11.3.

Consideration No:	One must consider:
1	that users can present their expertise and differentiate themselves from one another.
2	that users can associate themselves with others.
3	that users can access all the content stored within the system (where possible).
4	that all the relationships between the users, content and communications are formed.
5	that users can access the Social Media tool independent of which device they choose to use.
6	that core meta-data such as author, creation and location are captured.
7	that structured tagging is used where there is a requirement for content to have such meta data.
8	that unstructured tagging is used to provide an opportunity for additional relationships to be formed.
9	that character limitation is used in situations where focus upon the communication needs to be maintained.
10	the provision of a notification system within a Social Media tool for user activity and to ensure users are able determine their notification preferences.
11	how to take advantage of the fact that 'richer media' can aid browsing and the definition of the topic of communication.

Table 11.3: Summary of the Considerations Elicited from SM Literature

With both the requirements and considerations elicited, a Social Media Approach to support Engineering Design Communication was proposed (Chapter 6). The approach consisted of a Communication Process (Figure 11.2), Engineering Design Communication matrix (Table 6.1) and twenty-nine Social Media features (Tables 6.2, 6.3, 6.5, 6.5 & 6.6). Each stage of the communication process was discussed in detail with reference to how it meets both the requirements and considerations.

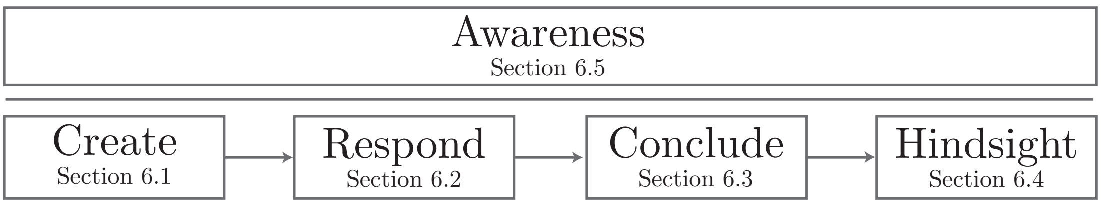


Figure 11.2: The Communication Process of the SM Framework to Support EDC

This Social Media Approach was then instantiated within a tool known as PartBook and utilises modern web-technologies such as PHP, HTML 5, CSS3 and JavaScript (Figure 11.3). The development of PartBook has been described in Chapter 7 and included internal iterations as it co-evolved with the requirements and considerations as well as an industrial trial. The trial generated six actions in order to improve the tool (see Table 7.5).

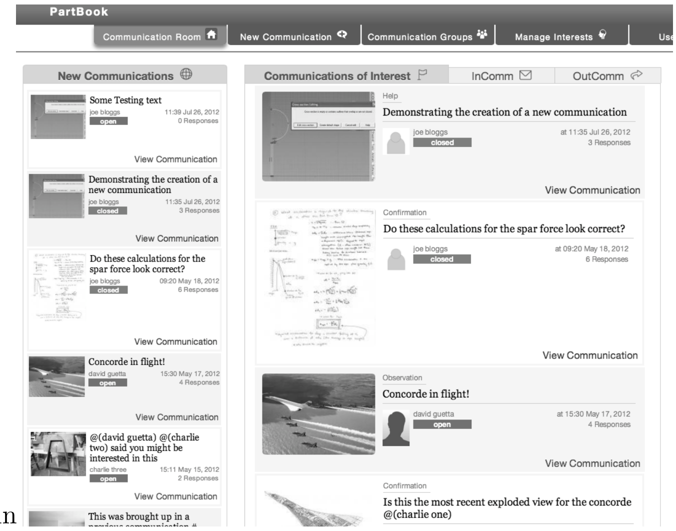


Figure 11.3: PartBook

PartBook was implemented within an eleven week Formula Student project (see Chapter 8). The study was discussed in detail with an initial team/project profiling exercise highlighting the multi-disciplinary and distributed nature of the project despite the common perception that it is a collocated project. As with Research Question One, the validity of the considerations in taking a Social Media approach were assessed through interviews aimed specifically to ascertain the validity of the considerations, a questionnaire to gather feedback on PartBooks functionality and the captured PartBook communications.

This analysis led to six considerations being deemed valid, four partially valid and one having insufficient data (Summarised in Table 9.38). The analysis also provided four key insights into the application of Social Media:

1. The importance engineers place on having accessibility to all the communications within the system (see Section 9.3.3).
2. The use of structured and unstructured tags does provide the ability to capture multiple facets of a communication (see Section 9.3.4, 9.3.7-8).
3. There is a significant challenge in developing an appropriate notification system that does not overload the engineer with information yet provides enough information for engineers to be made aware of potential communication to partake in (see Section 9.3.10).
4. The use of multi-media not only to support the current communication but also as a differentiator between communications and for search & retrieval (see Section 9.3.11).

This closes the work performed in answering Research Question Two.

11.3 Research Question Three

To answer Research Question Three, a secondary analysis of the generated dataset was performed. This assessed the impact of the Social Media Approach and discussed potential future impact relating to the previously defined terms Engineering Work, Engineering Records and Engineering Project Management. The analysis in relation to Engineering Work has shown that the implementation of a new communication tool does not effect the volume of communication across the project and that the engineers were able to quickly understand how to use the tool (see Figure 10.1). There were also indications that the creation of an Engineering Design Communication is potentially 2-3 minutes quicker within PartBook than it would of been using E-Mail (see Figure 10.2). The increase in computer-mediated collaboration amongst the team was also demonstrated when compared with E-Mail, where an almost three-fold increase in the average degree between the engineers was recorded (see Figure 10.3).

Referring back to the analysis performed to validate both the requirements and considerations, the feedback from the engineers showed that multi-threaded communication was a key feature that supported their Engineering Design Communications and hence Engineering Work (see Section 9.2.15). The engineers also made significant use of imagery in their discussions the highlighted the importance of images for search & retrieval purposes (see Sections 9.2.3 & 9.3.11). In addition, there were strong indications from the engineers that the captured communications would be potentially useful for future engineering projects (see Figure 9.1.

In terms of Engineering Records, patterns were identified in the purposes of communication and the Engineering Record it pertained to, which has led to the suggestion that areas of particular focus can be identified (see Figure 10.4). Also, contrasting behaviour in the cumulative frequencies of communications with respect to the various Engineering Records was also observed and it was hypothesised that this could potentially identify the stages of a project (see Figure 10.5).

Looking at Engineering Project Management, it has been identified that there are levels of normality with respect to the collaboration and typical number of replies for particular purposes of communication. This could be used to highlight communications away from the norm and highlight them to project management as these may be areas of contention in product development (see Figure 10.6). Also, differences can be seen between various types of communication and when they occur along the project time-line. This may provide potentially useful insights into the current state/progress of a project that could be interpreted by project managers and lead to appropriate project management intervention (see Figure 10.7). This is alongside the potential identification of key knowledgeable engineers through the patterns generated by the capturing of the purposes and replies that an engineer makes, and engineering records the communication relate to (see Figures 10.8 & 10.9). This information could potentially aid project managers to plan future projects and to better manage their human resource. These results and discussion closes the work performed on Research Question 3.

11.4 Aim

In summary, this research has answered Research Question One by creating a validated list of requirements for supporting Engineering Communication. It has answered Research Question Two by creating a validated list of considerations when undertaking a Social Media Approach as well as the creation of an Social Media Approach to support Engineering Design Communication. Research Question Three has been answered through evaluating the impact that a Social Media Approach has had on an Engineering Project with respect to Engineering Work, Engineering Records and Engineering Project Management. Thus, it is argued that this research has achieved the aim, to investigate how Social Media can be used to support Engineering Design Communication and has led to the contribution to knowledge of:

Contribution to Knowledge

A validated and evaluated Social Media Approach to Support Engineering Design Communication.

Which consists of a created:

1. set of Requirements in order to Support Engineering Design Communication
2. set of Considerations when taking a Social Media Approach
3. Social Media Approach to Support Engineering Design Communication
4. custom-built tool instantiating the Social Media Approach (PartBook)

All of which, has been created as part of a piece of prescriptive research within the field of Engineering Design Communication.

11.5 Limitations

Although the claim to the contribution to knowledge has been made, one has to recognise that there remains limitations to the research that has been conducted. Even though, the study has been performed within a project that attempts to reflect a 'real-life' project it has to be highlighted that the study was within an academic environment. It remains to be seen if such results are also seen within an industrial context and is a clear area for future research.

It is also interesting to note that the background information provided by the engineers highlighted that they were all familiar with Social Media tools and the associated functionalities. Therefore, this could be a reason for a high speed of uptake. This may not be the case for a industrial environment where further training may be required for engineers who may be unfamiliar. Although, it could be argued that the study could reflect a engineering company in 5-10 years time whereby a majority of the engineering team are familiar with the use of Social Media tools.

In addition, even though every precaution had been taken to ensure a usable tool instantiating the requirements was produced, there was substantial evidence to suggest that usability had a clear effect on the results produced. However, it is important that the research field requires these initial tool studies in order to build and develop from and to then produce potentially more reliable metrics.

11.6 Future Work

Although the main focus of this research has been to investigate how Social Media can be used to support Engineering Design Communication. A number of potential avenues for future research has been identified. This section summarises four avenues for future research.

11.6.1 Continued Development of the Tool

It has shown that prescriptive research can be performed successfully within the Engineering Design Communication field. In addition, the requirements, considerations and Social Media

Approach, as well as the PartBook tool can now be the fundamental building block for future research into supporting Engineering Design Communication. It has been highlighted that usability of the tool was a significant factor that needed to be considered when analysing the results. Therefore, a repeat of the study with an iteration of the PartBook tool would lead to potentially more consistent results across the engineers using the tool. Again, this was one of the main reasons for using open-source web standards. Thus, the potential future Research Question is one of how does improving the usability of a Social Media tool further improve the support for Engineering Design Communication?

11.6.2 Continued Validation of the Requirements

It is recognised that one study has been used in order to validate and evaluate the Social Media approach and that further studies are required, hence the use of the Formula Student project as it enables repeatability due to the event being held every year and with many engineering universities involved. This is in addition to further development of the Social Media tool so that it can overcome the usability issues present within this thesis.

Future research is also required into understanding how the requirements for supporting Engineering Design Communication could be validated within a major industrial setting. It may the case that certain aspects could be trialled in currently supported software (i.e. E-Mail). For example, the purpose of an E-Mail could be added to the subject line of that E-Mail. This has already been attempted by the author [Gopsill et al., 2013b]. Therefore, the Research Question discussed here is one of how can one further validate the requirements for supporting Engineering Design Communication in both an academic and industrial setting?

11.6.3 Re-use of Engineering Design Communications

Another aspect to consider is the re-use of these now stored communications along with their relationship to Engineering Work & Records. Now that there is a dataset of past communications, it would be interesting to see how they could be re-used for future Formula Student projects. Examples could be the understanding of how the engineers re-use the communications through search & retrieval, and how one could identify best practice and/or lessons learned that could be used in the following projects.

In addition, it would be interesting to understand how the re-use of captured communications compares and contrasts with currently employed knowledge management, lesson-learned and design rationale systems, such as IBIS and DRed [Hu et al., 2000, Bracewell et al., 2004]. Thus, the Research Question posed here is how can Engineering Design Communication be re-used in future Engineering Projects?

11.6.4 Support Engineering Project Management

The final aspect to be highlighted is the potential in improving the understanding of the status of an Engineering Project. Chapter 10 has shown that patterns can be seen between communications and the project plan, and stages thereof. Although no conclusive meaning behind the patterns could be determined at present. Eventhough, it is hypothesised that these patterns could identify/predict specific events within a project and identify the working dynamics of the engineers (i.e. experts and/or information sharers). Marsh [1997] (Figure 11.4) highlights that status, approach/method taken to solve a problem, tool help, programme management are some of the key knowledge & information requirements of engineers and it is argued that analysing the communications through statistical correlation, patterns in evolution and/or social network analysis could elicit this. Having this ability to understand the progression of the project in real-time could provide useful information to the engineering project managers and enable them to act pro-actively rather than reactively. Therefore, the future research question could be; Are there meaningful patterns within the Communications, Engineering Work & Engineering Records that could aid Engineering Project Management?

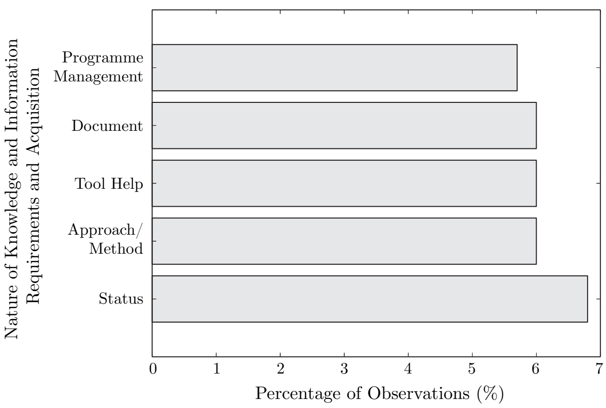


Figure 11.4: Top 5 of 30 Knowledge and Information Requirements of Engineers (*Excerpt from:* [Marsh, 1997, p. 121], *Re-Illustrated*)

11.6.5 Summary of Future Work

This section has provided some brief insights into potential future avenues of research that can continue on from what has been presented in this thesis. The areas involve the continued development of the tool, continued validation of the requirements, re-use of Engineering Design Communication and support for Engineering Project Management. Each has led to a future Research Question, which are highlighted in Table 11.4.

Future Research Question
How does improving the usability of a Social Media tool further improve the support for Engineering Design Communication?
How can one further validate the requirements for supporting Engineering Design Communication in both an academic and industrial setting?
How can Engineering Design Communication be re-used in future Engineering Projects?
Are there meaningful patterns within the Communications, Engineering Work & Engineering Records that could aid Engineering Project Management?

Table 11.4: Future Research Questions

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Appendix A

Formula Student Questionnaire

This appendix contains Table A.1, which contains the questions asked in the questionnaires used during the Formula Student Study.

Question	Type
Profiling Questionnaire	
Name	Free Text
Position	Free Text
How much experience have you had with Social Media tools? (For example, FaceBook, Twitter & LinkedIn)	Select from: daily use, weekly use, monthly use, yearly use, never
How long have you been using SM Tools?	Select from: 0 years, 1-3 years, 4-7 years, 8-9 years, 10+ years
How many SM tools do you use? (Facebook, Twitter, LinkedIn, Pinterest, Flickr etc...)	Select from: 1, 2, 3, 4, 5, 6, 7+
Do you use online storage (For example, DropBox and Google Drive)	Yes/No
What advantages do you see SM tools have when compared to previous methods of communication?	Free Text
What disadvantages do you see SM tools have when compared to previous methods of communication?	Free Text
What methods of communications did you use within the project? (can tick multiple)	Multiple Selection: E-Mail, Face-to-Face, Telephone, Facebook, Instant Messenger, Letter, SMS, other (free text)
PartBook Questionnaire	
PartBook was easy to use	Lickert Scale (1-9)
The purpose tag helped me understand what the engineer wanted from the communication.	Lickert Scale (1-9)
The response tags helped me understand the statements being made within the communications.	Lickert Scale (1-9)
The conclusion tag helped me understand the outcome of the communication.	Lickert Scale (1-9)
The initial set of purpose/response & conclusion tags were complete	Lickert Scale (1-9)
The character limit helped focus the discussion on the topic of interest.	Lickert Scale (1-9)
The character limit should be	Select From : decrease, increase, not exist
The uploading of an image helped me frame the question I was asking.	Lickert Scale (1-9)

Question	**Type**
The artefact tag helped identify what the image was when creating the communication.	Lickert Scale (1-9)
The focus tag helped identify the key point of the image when creating the communication.	Lickert Scale (1-9)
The images aided my understanding of the communication.	Lickert Scale (1-9)
The images helped me search and retrieve communications in PartBook.	Lickert Scale (1-9)
Please explain how/how not the use of images was useful to you.	Free Text
The multi-threaded feature helped the team to express different perspectives.	Lickert Scale (1-9)
Please explain:	Free Text
The communications on PartBook made me more aware of what was happening within the project and the progress being made	Lickert Scale (1-9)
I took part in communications that I would otherwise not have known about	Lickert Scale (1-9)
There were communications that could only have occurred easily within PartBook when compared to E-Mail	Lickert Scale (1-9)
There were communications that could only have occurred easily within PartBook when compared to FaceBook	Lickert Scale (1-9)
Can you explain your reasoning to the above two questions:	Free Text
What are the most useful features in PartBook?	Choose three according to preference from: Purpose Tag, Response Tag, Conclusion Tag, Multi-Threaded Discussions, Image Upload Requirement, Artefact Tag, Focus Tag, @(tag), Group Tagging, Linking Communications Together, Communication Accessible by All, InComm Box, OutComm Box, Interests Feed, Recent News, Character Limit, Help File, Other
If other selected, please provide details:	Free Text
What are the least useful features in PartBook?	Choose three according to preference from: Purpose Tag, Response Tag, Conclusion Tag, Multi-Threaded Discussions, Image Upload Requirement, Artefact Tag, Focus Tag, @(tag), Group Tagging, Linking Communications Together, Communication Accessible by All, InComm Box, OutComm Box, Interests Feed, Recent News, Character Limit, Help File, Other
If other selected, please provide details:	Free Text
To improve PartBook development should focus on features or usability?	Lickert Scale (Features or Usability)
Directing a communication with the @ feature was useful for ensuring I get a response to my communication.	Lickert Scale (1-9)
If you were to search for a communication which tags would you likely use (can tick multiple)	Multiple Selection: Purpose, Artefact Tag, Focus, Product, Part, Project, Activity, Lifecycle Stage, Group hash tag, By Person, Suggest Tag (free text)

Question	**Type**
What features would you like to see in the next iteration of Part-Book	Free Text
Systems Usability Scale Questions	
I think that I would like to use this system frequently	Lickert Scale (1-5)
I found the system unnecessarily complex	Lickert Scale (1-5)
I thought the system was easy to use	Lickert Scale (1-5)
I think that I would need the support of a technical person to be able to use this system	Lickert Scale (1-5)
I found the various features in this system were well integrated	Lickert Scale (1-5)
I thought there were was too much inconsistency in this system	Lickert Scale (1-5)
I would imagine that most people would learn to use this system very quickly	Lickert Scale (1-5)
I found the system very cumbersome to use	Lickert Scale (1-5)
I felt very confident using the system	Lickert Scale (1-5)
I needed to learn a lot of things before I could get going with this system	Lickert Scale (1-5)

Table A.1: Questionnaire use in the Formula Student Study

Appendix B

Code Snippets

This appendix provides the database schema for PartBook and some exemplar code that has been created for this thesis.

B.1 PartBook Database Schema

Figures B.1 & B.2 provide an overview of the final set of tables and their relationships between one another that was used by the PartBook tool. Extra activity monitoring tables used for analysis have been omitted for clarity.

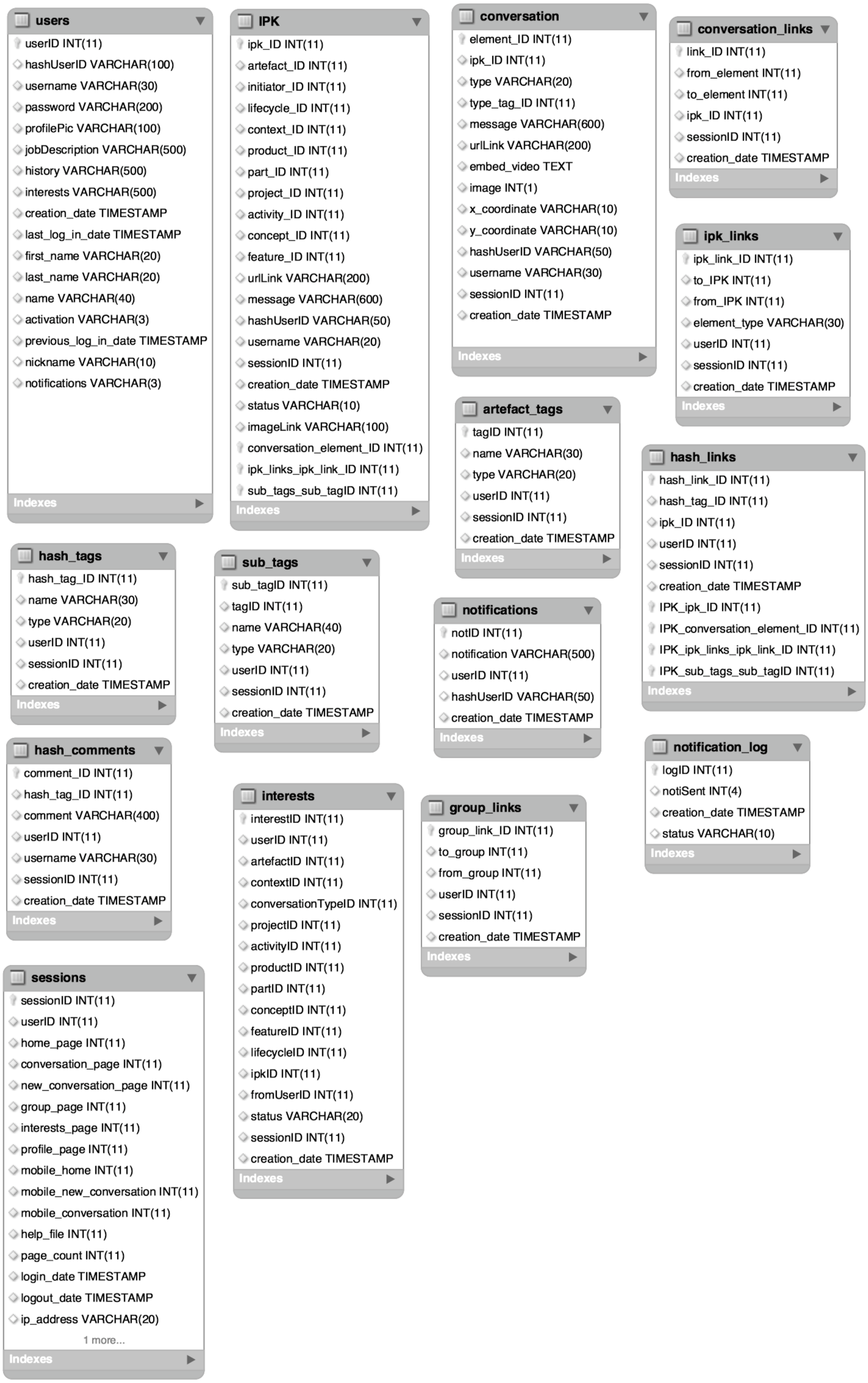

Figure B.1: The MySQL database tables used in PartBook

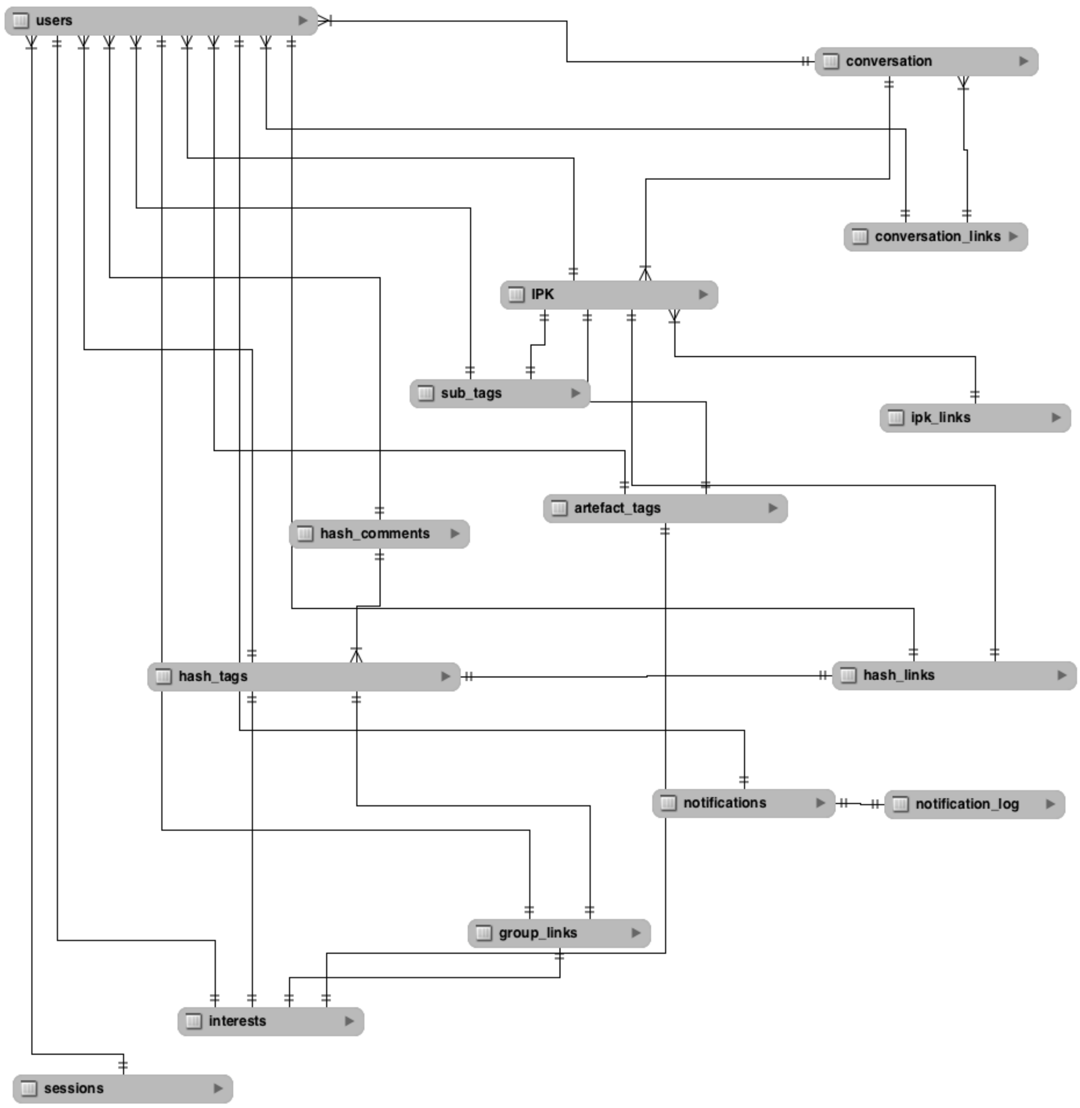

Figure B.2: Relationships between PartBook Tables

B.2 Example Web Page

Provided here is one of the web page files used in PartBook. More specifically, it is the file that generates the new communication web page (Figure 7.4b).

```
<?php

include_once 'php/core.php';
include_once 'php/new_conversation.php';

list ($userID, $sessionID, $username) = check_user_log();
// echo "userID = $userID , sessionID = $sessionID , username = $username"
$header = create_header($username);
$footer = create_footer();
$navigation = create_navigation("create_conversation");

include_once '../../PB_SQL_Connect/connect_to_mysql.php';

mysql_query("UPDATE sessions SET new_conversation_page = new_conversation_page +
     1 WHERE sessionID='$sessionID' LIMIT 1", $con);
mysql_query("UPDATE sessions SET page_count = page_count + 1 WHERE sessionID='
    $sessionID' LIMIT 1", $con);

$sql_insert = "INSERT INTO create_time (user_id, type, date) VALUES ('$userID','
    accessed',now())";

if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
}else{}

$artefact_tags = retrieveTags("artefact_type", $con);
$initiator_tags = retrieveTags("initiator", $con);
$lifecycle_tags = retrieveTags("lifecycle", $con);
$product_tags = retrieveTags("product", $con);
$concept_tags = retrieveTags("concept", $con);
$project_tags = retrieveTags("project", $con);

mysql_close($con);

?>

<!DOCTYPE html>
<html lang="en">
<head>
 <meta charset="utf-8" />
 <title>PartBook - New Conversation</title>
 <meta name="generator" content="BBEdit 10.1" />
 <link href="css/core.css" rel="stylesheet" />
 <link href="css/new_conversation.css" rel="stylesheet" />

 <script src="./js/jquery.js"></script>
 <script type="text/javascript">

 // Switching between Artefact types - Pressing the Add New Type Button
  function newArtefactTag(option)
  {
```

```
  if (option == "1") {
   document.getElementById('artefact_type_placeholder').innerHTML = '<input type="text" id="artefact_type" name="artefact_type" required placeholder="New Artefact Type:" value="" /><button onclick="newArtefactTag(2)">Tag List</button>';
   document.getElementById('artefact_context_placeholder').innerHTML = '<input type="text" id="context" name="context" required placeholder="New Focus:" value="" />';
  }
  if (option == "2") {
   document.getElementById('artefact_type_placeholder').innerHTML = '<select name="artefact_type" class="formFields" id="artefact_type" onchange="selectedType()"><option value="">Select an Artefact Type</option><?php echo $artefact_tags; ?></select><button onclick="newArtefactTag(1)">Add New Tag</button>';
   document.getElementById('artefact_context_placeholder').innerHTML = '';
  }
 }
// Pressing the add New Focus tag
 function newContextTag(option)
 {
  if (option == "1") {
   document.getElementById('artefact_context_placeholder').innerHTML = '<input type="text" id="context" name="context" required placeholder="New Focus:" value="" /><button onclick="newContextTag(2)">Return to List</button>';
  }
  if (option == "2") {
   var selected = $("#artefact_type")[0].value;
   if (selected == "NULL") {
    document.getElementById('artefact_context_placeholder').innerHTML = '';
   } else {
    $.ajax({
     type: "GET",
     url: "php/sub_tags.php",
     data: "selected="+selected,
     success: function(result) {
      if (result) {
       document.getElementById('artefact_context_placeholder').innerHTML = '<select name="context" class="formFields" id="context"><option value="NULL">What\'s the Focus?</option>'+result+'</select><button onclick="newContextTag(1)">Add New Focus</button>';
      } else {
       document.getElementById('artefact_context_placeholder').innerHTML = "Failed to Connect to Script";
      }
     }
    });
   }
  }
 }
 // Selecting an Artefact Type
 function selectedType()
 {
  var selected = $("#artefact_type")[0].value;
  if (selected == "") {
```

```
   document.getElementById('artefact_context_placeholder').innerHTML = '';
  } else {
   $.ajax({
    type: "GET",
    url: "php/sub_tags.php",
    data: "selected="+selected,
    success: function(result) {
     if (result) {
      document.getElementById('artefact_context_placeholder').innerHTML = '<
          select name="context" class="formFields" id="context"><option value
          ="">What\'s the Focus?</option>'+result+'</select><button onclick="
          newContextTag(1)">Add New Focus</button>';
     } else {
      document.getElementById('artefact_context_placeholder').innerHTML = "
          Failed to Connect to Script";
     }
    }
   });
  }
 }
 // Pressing the new Initiator Button
 function newInitiatorTag(option)
 {
  if (option == "1") {
   document.getElementById('initiator_placeholder').innerHTML = '<input type="
       text" id="initiator" name="initiator" required placeholder="Context:"
       value="" /><button onclick="newInitiatorTag(2)">Return to List</button
       >';
  }
  if (option == "2") {
   document.getElementById('initiator_placeholder').innerHTML = '<select name="
       initiator" class="formFields" id="initiator" ><option value="NULL">Type
       of Conversation</option><?php echo $initiator_tags; ?></select><button
       onclick="newInitiatorTag(1)">New Conversation</button>';
  }
 }
 // Pressing the new Lifecycle Phase button
 function newLifecycleTag(option)
 {
  if (option == "1") {
   document.getElementById('lifecycle_placeholder').innerHTML = '<input type="
       text" id="lifecycle" name="lifecycle" placeholder="New Lifecycle Tag:"
       value="" /><button onclick="newLifecycleTag(2)">Return to List</button
       >';
  }
  if (option == "2") {
   document.getElementById('lifecycle_placeholder').innerHTML = '<select name="
       lifecycle" class="formFields" id="lifecycle" ><option value="NULL">
       Lifecycle Stage</option><?php echo $lifecycle_tags; ?></select><button
       onclick="newLifecycleTag(1)">New Lifecycle Stage</button>';
  }
 }
 // The actual upload
 function upload()
 {
  var image = $("#imageUpload")[0].files[0];
```

```
    var artefact_type = $("#artefact_type")[0].value;
    var context = $("#context")[0].value;
    var initiator = $("#initiator")[0].value;
    var message = $("#message")[0].value;
    var lifecycle = $("#lifecycle")[0].value;
    var product = $("#product")[0].value;
    var part = $("#part")[0].value;
    var project = $("#project")[0].value;
    var activity = $("#activity")[0].value;
    var concept = $("#concept")[0].value;
    var feature = $("#feature")[0].value;
    var urlLink = $("#urlLink")[0].value;

    if (!image || artefact_type == "" || context == "" || initiator == "" || message == "" || context == "" || artefact_type == "" ) {
     document.getElementById('message_placeholder').innerHTML = '<div id="div_message"></div>';
    } else {
     // document.getElementById('message_placeholder').innerHTML = '<div id="div_message"></div>';
     //$('#div_message').append('<img alt="loading" src="site_images/loading.gif" style="width:25%;"/>');
     //$('#div_message').append('Image Available <br />');
     //$('#div_message').append('Artefact Variable = '+artefact_type+'<br />');
     //$('#div_message').append('Context Variable = '+context+'<br />');
     //$('#div_message').append('Initiator Variable = '+initiator+'<br />');
     //$('#div_message').append('Message Variable = '+message+'<br />');
     //$('#div_message').append('Lifecycle Variable = '+lifecycle+'<br />');
     //$('#div_message').append('product = '+product+'<br />');
     //$('#div_message').append('part = '+part+'<br />');
     //$('#div_message').append('project = '+project+'<br />');
     //$('#div_message').append('activity = '+activity+'<br />');
     //$('#div_message').append('concept = '+concept+'<br />');
     //$('#div_message').append('feature = '+feature+'<br />');
     //$('#div_message').append('URL link = '+urlLink+'<br />');

     document.getElementById('div_createNew').innerHTML = '<img alt="loading" src="site_images/loading.gif" style="margin-left:40%; width:20%;" />';
     $('#div_createNew').append('<progress id="progress" value="0" style="margin-left:20%; width:60%;" />');
     $('#div_createNew').append('<h4 style="width:100%; text-align:center;">Creating New Communication...</h4>');

     var formData = new FormData();

     formData.append("imageUpload", image);
     formData.append("artefact_type", artefact_type);
     formData.append("context", context);
     formData.append("initiator", initiator);
     formData.append("message", message);
     formData.append("lifecycle", lifecycle);
     formData.append("product", product);
     formData.append("part", part);
     formData.append("project", project);
     formData.append("activity", activity);
     formData.append("concept", concept);
```

```
    formData.append("feature", feature);
    formData.append("urlLink", urlLink);


    $("#progress").removeAttr("value");

    var oXHR = new XMLHttpRequest();
    oXHR.upload.addEventListener("progress", function(e) {
           // update the progress bar accordingly
           $("#progress").attr("max", e.total);
     $("#progress").attr("value", e.loaded);
       });
    oXHR.open("POST", "php/create_conversation.php");
    oXHR.onreadystatechange = function(){
    if (oXHR.readyState == 4){
     $('#div_createNew').append('<h4 style="width:100%; text-align:center;">Communication Created - You will be taken back to the home screen</h4>');
     document.location.href = "home.php";
    }};
    oXHR.send(formData);

   }

   if (!image) {
    $('#div_message').append('- Please Select an Image <br/ >');
   }
   if (artefact_type == "") {
    $('#div_message').append('- Please Enter an Artefact Type <br/ >');
   }
    if (context == "") {
    $('#div_message').append('- Please Enter the Context <br/ >');
   }
   if (initiator == "") {
    $('#div_message').append('- Please Enter the Type of Conversation <br/ >');
   }
   if (message == "") {
    $('#div_message').append('- Please Enter your message <br/ >');
   }
  }
 // --------------------------------------------------------------
 function dropDowns(option)
 {
  if (option == "1") { // Product Part
   $.ajax({
    type: "GET",
    url: "php/main_tags.php",
    data: "type=product",
    success: function(result) {
     if (result) {
      document.getElementById('product_placeholder').innerHTML = '<select name="product" class="formFields" id="product" onchange="subTags(1)" ><option value="">Select a Product</option>'+result+'</select>';
      document.getElementById('part_placeholder').innerHTML = '<input name="part" id="part" type="hidden" value="" /><button onclick="newCPP(1)">New Product</button>';
```

```
      } else {
       document.getElementById('product_placeholder').innerHTML = "Failed to Connect to Script";
      }
     }
    });
   }
   if (option == "2") { // Project Activity
    $.ajax({
     type: "GET",
     url: "php/main_tags.php",
     data: "type=project",
     success: function(result) {
      if (result) {
       document.getElementById('project_placeholder').innerHTML = '<select name="project" class="formFields" id="project" onchange="subTags(2)" ><option value="">Select a Project</option>'+result+'</select>';
       document.getElementById('activity_placeholder').innerHTML = '<input name="activity" id="activity" type="hidden" value="" /><button onclick="newCPP(2)">New Project</button>';
      } else {
       document.getElementById('project_placeholder').innerHTML = "Failed to Connect to Script";
      }
     }
    });
   }
   if (option == "3") { // Concept Feature
    $.ajax({
     type: "GET",
     url: "php/main_tags.php",
     data: "type=concept",
     success: function(result) {
      if (result) {
       document.getElementById('concept_placeholder').innerHTML = '<select name="concept" class="formFields" id="concept" onchange="subTags(3)" ><option value="">Select a Concept</option>'+result+'</select>';
       document.getElementById('feature_placeholder').innerHTML = '<input name="feature" id="feature" type="hidden" value="" /><button onclick="newCPP(3)">New Concept</button>';
      } else {
       document.getElementById('concept_placeholder').innerHTML = "Failed to Connect to Script";
      }
     }
    });
   }
  }
  function newCPP(option)
  {
   if (option == "1") { // Product Part
    document.getElementById('product_placeholder').innerHTML = '<input type="text" id="product" name="product" placeholder="New Product:" value="" />';
    document.getElementById('part_placeholder').innerHTML = '<input type="text" id="part" name="part" placeholder="New Part:" value="" /><button onclick
```

```
      ="dropDowns(1)">Return to List</button>';
 }
 if (option == "2") { // Project Activity
  document.getElementById('project_placeholder').innerHTML = '<input type="
      text" id="project" name="project" placeholder="New Product:" value=""
      />';
  document.getElementById('activity_placeholder').innerHTML = '<input type="
      text" id="activity" name="activity"  placeholder="New Activity:" value
      ="" /><button onclick="dropDowns(2)">Return to List</button>';
 }
 if (option == "3") { // Concept Feature
  document.getElementById('concept_placeholder').innerHTML = '<input type="
      text" id="concept" name="concept"  placeholder="New Concept:" value=""
      />';
  document.getElementById('feature_placeholder').innerHTML = '<input type="
      text" id="feature" name="feature"  placeholder="New Feature" value=""
      /><button onclick="dropDowns(3)">Return to List</button>';
 }
}
function subTags(option)
{
 if (option == "1") { // product, part
  var value = $("#product")[0].value;
  if (value == "") {
   document.getElementById('part_placeholder').innerHTML = '<input name="part"
       id="part" type="hidden" value="" /><button onclick="newCPP(1)">New
      Product</button>';
  } else {
   document.getElementById('part_placeholder').innerHTML = '<img alt="loading"
       src="site_images/loading.gif" style="width:100%;"/>';
   $.ajax({
    type: "GET",
    url: "php/sub_tags.php",
    data: "selected="+value,
    success: function(result) {
     if (result) {
      document.getElementById('part_placeholder').innerHTML = '<select name="
          part" class="formFields" id="part"><option value="">Please Select a
          Part</option>'+result+'</select><button onclick="newSubTag(1)">New
          Part</button>';
     } else {
      document.getElementById('part_placeholder').innerHTML = "Failed to
          Connect to Script";
     }
    }
   });
  }
 }
 if (option == "2") { // project, activity
  var value = $("#project")[0].value;
  if (value == "") {
   document.getElementById('activity_placeholder').innerHTML = '<input name="
      activity" id="activity" type="hidden" value="" /><button onclick="
      newCPP(2)">New Project</button>';
  } else {
```

```
   document.getElementById('activity_placeholder').innerHTML = '<img alt="loading" src="site_images/loading.gif" style="width:100%;"/>';
   $.ajax({
    type: "GET",
    url: "php/sub_tags.php",
    data: "selected="+value,
    success: function(result) {
     if (result) {
      document.getElementById('activity_placeholder').innerHTML = '<select name="activity" class="formFields" id="activity"><option value="">Please Select an Activity</option>'+result+'</select><button onclick="newSubTag(2)">New Activity</button>';
     } else {
      document.getElementById('activity_placeholder').innerHTML = "Failed to Connect to Script";
     }
    }
   });
  }
 }
 if (option == "3") { // project, activity
  var value = $("#concept")[0].value;
  if (value == "") {
   document.getElementById('feature_placeholder').innerHTML = '<input name="feature" id="feature" type="hidden" value="" /><button onclick="newCPP(3)">New Concept</button>';
  } else {
   document.getElementById('feature_placeholder').innerHTML = '<img alt="loading" src="site_images/loading.gif" style="width:100%;"/>';
   $.ajax({
    type: "GET",
    url: "php/sub_tags.php",
    data: "selected="+value,
    success: function(result) {
     if (result) {
      document.getElementById('feature_placeholder').innerHTML = '<select name="feature" class="formFields" id="feature"><option value="">Please Select a Feature</option>'+result+'</select><button onclick="newSubTag(3)">New Feature</button>';
     } else {
      document.getElementById('feature_placeholder').innerHTML = "Failed to Connect to Script";
     }
    }
   });
  }
 }
}
function newSubTag(option)
{
 if (option == "1") {
  document.getElementById('part_placeholder').innerHTML = '<input type="text" id="part" name="part" placeholder="New Part:" value="" /><button onclick="subTags(1)">Return to List</button>';
 }
 if (option == "2") {
```

```
    document.getElementById('activity_placeholder').innerHTML = '<input type="text" id="activity" name="activity" placeholder="New Activity:" value="" /><button onclick="subTags(2)">Return to List</button>';
   }
   if (option == "3") {
    document.getElementById('feature_placeholder').innerHTML = '<input type="text" id="feature" name="feature" placeholder="New Feature:" value="" /><button onclick="subTags(3)">Return to List</button>';
   }
  }
  // -------------------------------------------------------------
  function wordCount()
  {
   var characterMax = 250;
   var currentCharacters = $("#message")[0].value.length;
   var remainingCharacters = characterMax - currentCharacters
   document.getElementById('characterCount').innerHTML = remainingCharacters+" Characters Remaining";
  }
  // -------------------------------------------------------------
  function revealInfo(toLocation, informationBox)
  {
   // Position it in the x coordinate
      var x_direction = document.getElementById(toLocation).offsetLeft + document.getElementById(toLocation).offsetWidth + 5;
      document.getElementById(informationBox).style.left = x_direction+'px';
      // Position in the y coordinate
      var y_direction = document.getElementById(toLocation).offsetTop;
      document.getElementById(informationBox).style.top = y_direction+'px';
      // reveal
      document.getElementById(informationBox).style.display = 'inline';
  }
  function hideInfo(informationBox)
     {
      document.getElementById(informationBox).style.display = 'none';
     }
 </script>

</head>

<body>

<?php
 echo $header;
 echo $navigation;
?>

<div id="message_placeholder">
</div>

<div id="divCreateHeader">
 Generate a New Communication
</div>

<div id="div_createNew">

```

```
<p id="stepThree" onmouseover="revealInfo('stepThree', 'stepThreeInfo')"
    onmouseout="hideInfo('stepThreeInfo')"><b>Step 1</b> - What communication
    do you want to have?</p>
<div id="formBox">
 <div id="initiator_placeholder">
  <select name="initiator" class="formFields" id="initiator" >
   <option value="">Type of Communication</option>
   <?php echo $initiator_tags; ?>
  </select>
  <button onclick="newInitiatorTag(1)">New Conversation</button>
 </div>
 <textarea name="message" id="message" placeholder="Message:" onkeypress="
     wordCount()" maxlength="250"></textarea>
 <div id="characterCount">250 Characters Remaining</div>
</div>

<p id="stepOne" onmouseover="revealInfo('stepOne', 'stepOneInfo')" onmouseout="
    hideInfo('stepOneInfo')"><b>Step 2</b> - Please select an image of the
    object (512kB max)</p>
<div id="formBox">
 <input type="file" name="imageUpload" id="imageUpload" size="50" accept="image
     /*"/>
 <input type="text" id="urlLink" name="urlLink" placeholder="Add url link to
     object (optional)" value="" />
</div>


<p id="stepTwo" onmouseover="revealInfo('stepTwo', 'stepTwoInfo')" onmouseout="
    hideInfo('stepTwoInfo')"><b>Step 3</b> - Please classify and describe the
    object</p>
<div id="formBox">
 <div id="artefact_type_placeholder">
  <select name="artefact_type" class="formFields" id="artefact_type" onchange="
      selectedType()">
   <option value="">Select an Artefact Type</option>
   <?php echo $artefact_tags; ?>
  </select>
  <button onclick="newArtefactTag(1)">Add New Type</button>
 </div>
 <div id="artefact_context_placeholder">
  <input name="context" id="context" type="hidden" value="NULL"/>
 </div>
</div>


<!-- <p id="stepThree" onmouseover="revealInfo('stepThree', 'stepThreeInfo')"
    onmouseout="hideInfo('stepThreeInfo')"><b>Step 3</b> - What communication
    do you want to have?</p>
<div id="formBox">
 <div id="initiator_placeholder">
  <select name="initiator" class="formFields" id="initiator" >
   <option value="">Type of Communication</option>
   <?php echo $initiator_tags; ?>
  </select>
  <button onclick="newInitiatorTag(1)">New Conversation</button>
 </div>
```

```
 <textarea name="message" id="message" placeholder="Message:" onkeypress="wordCount()" maxlength="250"></textarea>
 <div id="characterCount">250 Characters Remaining</div>
</div> -->

   <!--
<p id="stepFour" onmouseover="revealInfo('stepFour', 'stepFourInfo')" onmouseout="hideInfo('stepFourInfo')"><b>Step 4</b> - Classify for Search and Retrieval <br/ >(Where Applicable)</p>
<div id="formBox">
 <div id="columns">
  <p>Project Classification</p>
  <div id="classMenus">
   <div id="project_placeholder">
    <select name="project" class="formFields" id="project" onchange="subTags(2)" >
     <option value="">Select Project</option>
      <?php echo $project_tags; ?>
    </select>
   </div>
   <div id="activity_placeholder">
    <input name="activity" id="activity" type="hidden" value="" />
    <button onclick="newCPP(2)">New Project</button>
   </div>
  </div>
 </div>
 <div id="columns">
  <p>Product Classification</p>
  <div id="classMenus">
   <div id="product_placeholder">
    <select name="product" class="formFields" id="product" onchange="subTags(1)" >
     <option value="">Select Product</option>
     <?php echo $product_tags; ?>
    </select>
   </div>
   <div id="part_placeholder">
    <input name="part" id="part" type="hidden" value="" />
    <button onclick="newCPP(1)">New Product</button>
   </div>
  </div>
 </div>
 <div id="columns">
  <p>Concept Classification</p>
  <div id="classMenus">
   <div id="concept_placeholder">
    <select name="concept" class="formFields" id="concept" onchange="subTags(3)" >
     <option value="">Select Concept</option>
      <?php echo $concept_tags; ?>
    </select>
   </div>
   <div id="feature_placeholder">
    <input name="feature" id="feature" type="hidden" value="" />
    <button onclick="newCPP(3)">New Concept</button>
   </div>
```

```
   </div>
  </div>
  <div id="columns">
   <p>Lifecycle Classification</p>
   <div id="classMenus">
    <div id="lifecycle_placeholder">
     <select name="lifecycle" class="formFields" id="lifecycle" >
      <option value="">Lifecycle Stage</option>
      <?php echo $lifecycle_tags; ?>
     </select>
     <button onclick="newLifecycleTag(1)">New Lifecycle Stage</button>
    </div>
   </div>
  </div>
 </div> -->

 <button id="button_create" onclick="upload()">Create</button>


</div>



<?php
 echo $footer;
?>

<input type="hidden" id="lifecycle" value="" />
<input type="hidden" id="concept" value="" />
<input type="hidden" id="product" value="" />
<input type="hidden" id="project" value="" />
<input type="hidden" id="feature" value="" />
<input type="hidden" id="part" value="" />
<input type="hidden" id="activity" value="" />

<img alt="loading" src="site_images/loading.gif" style="display:none;"/>
<div class="infoBox" id="stepOneInfo">To create a new communication you must
    have a photo of the object of interest (.jpg format). If it is a file such
    as a report or CAD file then you can add the url of its position. Although
    you must still upload a screenshot of what you are doing.</div>
<div class="infoBox" id="stepTwoInfo">Please add tags that describe what the
    object is and what is the focus upon the object. For example, Object -
    Calculation and the Focus - Result</div>
<div class="infoBox" id="stepThreeInfo">Please assign the type of communication
    you wish to have and enter the question within the text box.</div>
<div class="infoBox" id="stepFourInfo">These tags are used for search and
    retrieval purposes. The communications do not have to be tagged against all
    these criteria. Only where deemed appropriate.</div>

</body>
</html>
```

B.3 Example Server Side Code

Provided here is one of the server side codes. More specifically, this code handles the generation of a new communication within PartBook.

```php
<?php

if ($_SERVER['REQUEST_METHOD'] != "POST") die ("No Variables");

// Retrieving the Variables
$artefact_type = $_POST['artefact_type'];
$context = $_POST['context'];
$initiator = $_POST['initiator'];
$message = $_POST['message'];
$classification_type = $_POST['classification_type'];
$classify_tag = $_POST['classify_tag'];
$classify_sub_tag = $_POST['classify_sub_tag'];
$lifecycle = $_POST['lifecycle'];

$product = $_POST['product'];
$part = $_POST['part'];
$concept = $_POST['concept'];
$feature = $_POST['feature'];
$project = $_POST['project'];
$activity = $_POST['activity'];

$urlLink = $_POST['urlLink'];

$message = trim($message);

if ($urlLink == ''){
 $urlLink = "NULL";
}


include_once '../../../PB_SQL_Connect/connect_to_mysql.php';
include_once 'core.php';
// Retrieve user information
list ($userID, $sessionID, $username, $hashUserID) = check_user_log();

// Retrieve IDs or create IDs from artefact_tags

$artefact_ID = artefact_tags($artefact_type, "artefact_type", $userID,
    $sessionID, $con);
$initiator_ID = artefact_tags($initiator, "initiator", $userID, $sessionID, $con
    );

if ($lifecycle == '') {
 $lifecycle_ID = 0;
} else {
 $lifecycle_ID = artefact_tags($lifecycle, "lifecycle", $userID, $sessionID,
     $con);
}
if ($product == '') {
 $product_ID = 0;
} else {
```

```
 $product_ID = artefact_tags($product, "product", $userID, $sessionID, $con);
}
if ($concept == '') {
 $concept_ID = 0;
} else {
 $concept_ID = artefact_tags($concept, "concept", $userID, $sessionID, $con);
}
if ($project == '') {
 $project_ID = 0;
} else {
 $project_ID = artefact_tags($project, "project", $userID, $sessionID, $con);
}

// Now Sub_Tags

$context_ID = sub_tags($context, $artefact_ID, 'context', $userID, $sessionID,
    $con);

if ($part == '') {
 $part_ID = 0;
} else {
 $part_ID = sub_tags($part, $product_ID, 'part', $userID, $sessionID, $con);
}
if ($activity == '') {
 $activity_ID = 0;
} else {
 $activity_ID = sub_tags($activity, $project_ID, 'activity', $userID, $sessionID
     , $con);
}
if ($feature == '') {
 $feature_ID = 0;
} else {
 $feature_ID = sub_tags($feature, $concept_ID, 'feature', $userID, $sessionID,
     $con);
}



// Uploading to the server

$sql_insert = "INSERT INTO IPK (artefact_ID, initiator_ID, lifecycle_ID,
    context_ID, product_ID, part_ID, project_ID, activity_ID, concept_ID,
    feature_ID, urlLink, message, hashUserID, username, sessionID, creation_date
    , status, imageLink) VALUES ('$artefact_ID','$initiator_ID','$lifecycle_ID
    ','$context_ID','$product_ID','$part_ID','$project_ID','$activity_ID','
    $concept_ID','$feature_ID','$urlLink','placeholder','$hashUserID','$username
    ','$sessionID',now(),'open','empty')";
if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
} else {
 $ipk_ID = mysql_insert_id();
}

// Create a Notification for everyone to see

```

```
$sql_insert = "INSERT INTO notifications (notification, userID, creation_date) VALUES ('New Communication Awaiting You: Communication Number $ipk_ID', '0', now() )";
if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
} else {}

$noti_message = htmlentities("<b>Message:</b> ", ENT_QUOTES);
$noti_message .= htmlentities($message, ENT_QUOTES);

$sql_insert = "INSERT INTO notifications (notification, userID, creation_date) VALUES ('$noti_message', '0', now() )";
if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
} else {}

// checking for initial tags
$message = hashTagCheck($message, 'expert_group', '#', $ipk_ID, $userID, $sessionID, $con);
$message = hashTagCheck($message, 'personal_group', '^', $ipk_ID, $userID, $sessionID, $con);
$message = hashTagCheck($message, 'task_group', '~', $ipk_ID, $userID, $sessionID, $con);
$message = linkIPKs($message, $ipk_ID, 'initiator', $userID, $sessionID, $con);
$message = sendIPK($message, $ipk_ID, $userID, $sessionID, $con);

$message = htmlentities($message, ENT_QUOTES);

mysql_query("UPDATE IPK SET message='$message' WHERE ipk_ID='$ipk_ID' LIMIT 1", $con);


$sql_insert = "INSERT INTO conversation (ipk_ID, type, type_tag_ID, message, urlLink, embed_video, image, x_coordinate, y_coordinate, hashUserID, username, sessionID, creation_date) VALUES ('$ipk_ID', 'initiator', '$initiator_ID', '$message', '$urlLink', 'NULL', '1', '450px','5px', '$hashUserID','$username','$sessionID', now())";
if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
} else {
 $convo_ID = mysql_insert_id();
}

// -------- Sorting out the image ------

$fileName = $_FILES['imageUpload']['name'];
$kaboom = explode('.', $fileName);
$fileExt = end($kaboom);
$fileExt = strtolower($fileExt);

//move_uploaded_file($_FILES['imageUpload']['tmp_name'], '../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'');

//include_once 'image_resize.php';
//$target_file = '../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'';
//$resized_file = '../ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'';
```

```
//$wmax = 200;
//$hmax = 200;

//ak_img_resize($target_file, $resized_file, $wmax, $hmax, $fileExt);

//chmod('../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'', 0644);
//chmod('../ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'', 0644);

//$fileLocation = 'ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'';
//mysql_query("UPDATE IPK SET imageLink='$fileLocation' WHERE ipk_ID='$ipk_ID' LIMIT 1", $con);


move_uploaded_file($_FILES['imageUpload']['tmp_name'], '../../../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'');

include_once 'image_resize.php';
$target_file = '../../../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'';
$resized_file = '../../../ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'';
$wmax = 200;
$hmax = 200;

ak_img_resize($target_file, $resized_file, $wmax, $hmax, $fileExt);

chmod('../../../ipk_images/Convo_original_'.$convo_ID.'.'.$fileExt.'', 0644);
chmod('../../../ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'', 0644);

$fileLocation = 'ipk_images/Convo_thumbnail_'.$convo_ID.'.'.$fileExt.'';
mysql_query("UPDATE IPK SET imageLink='$fileLocation' WHERE ipk_ID='$ipk_ID' LIMIT 1", $con);

$sql_insert = "INSERT INTO create_time (user_id, type, date) VALUES ('$userID','created',now())";

if (! mysql_query($sql_insert,$con)) {
 die('Error: ' . mysql_error());
}else{}


mysql_close($con);

// ------------------------------------------------------------------------------------------
// ------------------------------------------------------------------------------------------
// ------------------------------------------------------------------------------------------
// ------------------------------------------------------------------------------------------
```

```
function artefact_tags($tag, $type, $userID, $sessionID, $con)
{
 if (is_numeric($tag)) {
  return $tag;
 } else {
  $tag = htmlentities($tag, ENT_QUOTES);
  $sql_insert = "INSERT INTO artefact_tags (name, type, userID, sessionID, creation_date) VALUES ('$tag','$type','$userID', '$sessionID',now())";
  if (! mysql_query($sql_insert,$con)) {
   die('Error: ' . mysql_error());
  } else {
   $tag = mysql_insert_id();
   return $tag;
  }
 }
}

function sub_tags($tag, $link_tag, $type, $userID, $sessionID, $con)
{
 if (is_numeric($tag)) {
  return $tag;
 } else {
  $tag = htmlentities($tag, ENT_QUOTES);
  $sql_insert = "INSERT INTO sub_tags (tagID, name, type, userID, sessionID, creation_date) VALUES ('$link_tag','$tag','$type','$userID', '$sessionID', now())";
  if (! mysql_query($sql_insert,$con)) {
   die('Error: ' . mysql_error());
  } else {
   $tag = mysql_insert_id();
   return $tag;
  }
 }
}

function hashTagCheck($message, $type, $indicator, $ipk_ID, $userID, $sessionID, $con)
{
 $amended_message = $message;
 for($i = "0", $size = strlen($message); $i < $size; $i++) {
  // Find the start of the tag
  if(substr($message,$i,1) == $indicator) {
   $tag_start = $i+2;
   $temp_i = $i+2;
   $trigger = 0;
   // ----------- Running through to find the end of the tag ---------------
   for($temp_i; $temp_i < $size; $temp_i++) {
    // meets these criteria then it is the end of the string
    if( (substr($message,$temp_i,1) == ")") && ($trigger == 0) ) {
     $tag_end = $temp_i-$tag_start; // One back from the )
     $hash_tag = substr($message, $tag_start, $tag_end);
     $hash_tag = strtolower($hash_tag);
     $trigger = 1;

     if ($type == 'personal_group') {
```

```
       $sql = mysql_query("SELECT * FROM hash_tags WHERE name='$hash_tag' AND type='$type' AND userID='$userID'", $con);
      } else {
       $sql = mysql_query("SELECT * FROM hash_tags WHERE name='$hash_tag' AND type='$type'", $con);
      }

      $check = mysql_num_rows($sql);
      if ($check > 0) {
       // The hash_tag is present
       while($row = mysql_fetch_array($sql)){
        $hash_tag_ID = $row["hash_tag_ID"];
       }

       $sql_insert = "INSERT INTO hash_links (hash_tag_ID, ipk_ID, userID, sessionID, creation_date) VALUES ('$hash_tag_ID', '$ipk_ID', '$userID', '$sessionID', now())";
       if (! mysql_query($sql_insert,$con)) {die('Error: ' . mysql_error());} else { }

       if ($type == 'personal_group') {} else {
        $amended_message = str_replace(''.$indicator.'('.$hash_tag.')', '<a href="group.php?groupID='.$hash_tag_ID.'">'.$indicator.'('.$hash_tag.')</a>', $amended_message);
       }

      } else {

       $sql_insert = "INSERT INTO hash_tags (name, type, userID, sessionID, creation_date) VALUES ('$hash_tag', '$type', '$userID', '$sessionID', now())";
       if (! mysql_query($sql_insert,$con)) {
        die('Error: ' . mysql_error());
       } else {
        $hash_tag_ID = mysql_insert_id();
       }

       $sql_insert = "INSERT INTO hash_links (hash_tag_ID, ipk_ID, userID, sessionID, creation_date) VALUES ('$hash_tag_ID', '$ipk_ID', '$userID', '$sessionID', now())";
       if (! mysql_query($sql_insert,$con)) {die('Error: ' . mysql_error());} else { }

       if ($type == 'personal_group') {} else {
        $amended_message = str_replace(''.$indicator.'('.$hash_tag.')', '<a href="group.php?groupID='.$hash_tag_ID.'">'.$indicator.'('.$hash_tag.')</a>', $amended_message);
       }

      }
     }
    }
   }
  }
  return $amended_message;
 }
```

```
function linkIPKs($message, $ipk_ID, $element_type, $userID, $sessionID, $con)
{
 $amended_message = $message;
 for($i = "0", $size = strlen($message); $i < $size; $i++) {
  // Find the start of the tag
  if(substr($message,$i,1) == '*') {
   $tag_start = $i+2;
   $temp_i = $i+2;
   $trigger = 0;
   // ---------- Running through to find the end of the tag ---------------
   for($temp_i; $temp_i < $size; $temp_i++) {
    // meets these criteria then it is the end of the string
    if( (substr($message,$temp_i,1) == ")") && ($trigger == 0) ) {
     $tag_end = $temp_i-$tag_start; // One back from the )
     $hash_tag = substr($message, $tag_start, $tag_end);
     $trigger = 1;

     if (is_numeric($hash_tag)) {
      $sql_insert = "INSERT INTO ipk_links (to_IPK, from_IPK, element_type,
          userID, sessionID, creation_date) VALUES ('$hash_tag', '$ipk_ID', '
          $element_type', '$userID', '$sessionID', now())";
      if (! mysql_query($sql_insert,$con)) {die('Error: ' . mysql_error());}
          else { }

      $amended_message = str_replace('*('.$hash_tag.')', '<a href="conversation.
          php?ipk_ID='.$hash_tag.'">*('.$hash_tag.')</a>', $amended_message);

     }

    }
   }
  }
 }
 return $amended_message;
}

function sendIPK($message, $ipk_ID, $userID, $sessionID, $con)
{
 $amended_message = $message;
 for($i = "0", $size = strlen($message); $i < $size; $i++) {
  // Find the start of the tag
  if(substr($message,$i,1) == '@') {
   $tag_start = $i+2;
   $temp_i = $i+2;
   $trigger = 0;
   // ---------- Running through to find the end of the tag ---------------
   for($temp_i; $temp_i < $size; $temp_i++) {
    // meets these criteria then it is the end of the string
    if( (substr($message,$temp_i,1) == ")") && ($trigger == 0) ) {
     $tag_end = $temp_i-$tag_start; // One back from the )
     $hash_tag = substr($message, $tag_start, $tag_end);
     $trigger = 1;

     $sql = "SELECT * FROM users WHERE name='$hash_tag' OR nickname='$hash_tag'
         ORDER BY creation_date LIMIT 1 ";
```

```
     $sql = mysql_query($sql, $con); // connect database to get the user information
     $check = mysql_num_rows($sql);
     if ($check == 1) {
      while($row = mysql_fetch_array($sql)){
       $toUserID = $row["userID"];
      }

      $sql_insert = "INSERT INTO interests (userID, ipkID, fromUserID, status, sessionID, creation_date) VALUES ('$toUserID','$ipk_ID','$userID','sent','$sessionID',now())";
      if (! mysql_query($sql_insert,$con)) {
       die('Error: ' . mysql_error());
      } else {}

      // $amended_message = str_replace('@('.$hash_tag.')', '@('.$hash_tag.')', $amended_message);
      $amended_message = str_replace('@('.$hash_tag.')', '<b>@('.$hash_tag.')</b>', $amended_message);
      $notification = 'A Communication has been sent to your InComm Box';
      createNotification($notification, $toUserID, $con);

     }
    }
   }
  }
 }
 return $amended_message;
}

function createNotification($message, $userID, $con) {
 $sql_insert = "INSERT INTO notifications (notification, userID, creation_date) VALUES ('$message','$userID',now())";
 if (! mysql_query($sql_insert,$con)) {
  die('Error: ' . mysql_error());
 } else {}
}

?>
```

B.4 Raspberry Pi Python Monitoring

Provided here is the python code used to monitor the shared file space of the Formula Student team.

```
#!/usr/bin/env python

# -*- coding: utf-8 -*-
"""
Created on Tue Mar 26 14:55:46 2013

@author: James
"""

import os
```

```
# mysql connection scripts
import mysql.connector
from mysql.connector import errorcode
import shutil

def connect_to_database():
    try:
        cnx = mysql.connector.connect(user='*******',
                                      password='*******',
                                      host='*******',
                                      database='*******')
    except mysql.connector.Error as err:
        if err.errno == errorcode.ER_ACCESS_DENIED_ERROR:
            print("Something if wrong with your username or password")
        elif err.errno == errorcode.ER_BAD_DB_ERROR:
            print("Database does not exist")
        else:
            print(err)
    else:
        return cnx

def checkMonitorRecords(file, path, initialPathLength, cursor):
    fullFilepath = path+"/"+file # Create the full file path
    if path.__len__() > initialPathLength + 1:
        dir = "*******"+path[initialPathLength:]+"/"
    else:
        dir = "*******"

    if not os.path.exists(dir):
        os.makedirs(dir)

    file_name = fullFilepath[initialPathLength:]

    try:
        fileInformation = os.stat(fullFilepath)
    except IOError:
        print "Failed to Retrieve File Information"
    else:
        file_size = str(int(fileInformation.st_size))
        date_accessed_epoch = str(int(fileInformation.st_atime))
        date_modified_epoch = str(int(fileInformation.st_mtime))
        date_changed_epoch = str(int(fileInformation.st_ctime))
        ext = file.split('.')
        ext = ext[-1]
        cursor.execute("SELECT MAX(id) FROM fs_monitor WHERE file_name=%s", (
            file_name,))
        count = int(cursor.rowcount)
        if count == 0:
            cursor.execute("INSERT INTO fs_monitor (file_name, file_size,
                date_accessed_epoch, date_modified_epoch, date_changed_epoch,
                file_description, added_to_database) VALUES (%s, %s, %s, %s, %s,
                 %s, now()", (file_name, file_size, date_accessed_epoch,
                date_modified_epoch, date_changed_epoch, ext))
            file_id = str(cursor.lastrowid())
            toFilepath = dir+"("+file_id+")"+file
            shutil.copy2(fullFilepath,toFilepath)
```

```
            cursor.execute("UPDATE fs_monitor SET usb_path=%s WHERE id=%s)", (toFilepath, file_id))
        else:
            temp_id = cursor.fetchone()
            temp_id = str(temp_id[0])
            cursor.execute("SELECT * FROM fs_monitor WHERE id=%s", (temp_id,))
            row = cursor.fetchone()
            if row[7] == "TRUE" or row[5] < int(date_modified_epoch):
                cursor.execute("INSERT INTO fs_monitor (file_name, file_size, date_accessed_epoch, date_modified_epoch, date_changed_epoch, file_description, added_to_database) VALUES (%s, %s, %s, %s, %s, %s, now()", (file_name, file_size, date_accessed_epoch, date_modified_epoch, date_changed_epoch, ext))
                file_id = str(cursor.lastrowid())
                toFilepath = dir+"("+file_id+")"+file
                shutil.copy2(fullFilepath,toFilepath)
                cursor.execute("UPDATE fs_monitor SET usb_path=%s WHERE id=%s)", (toFilepath, file_id))
            elif row[4] < int(date_accessed_epoch) or row[6] < int(date_changed_epoch):
                cursor.execute("INSERT INTO fs_monitor (file_name, file_size, date_accessed_epoch, date_modified_epoch, date_changed_epoch, file_description, added_to_database) VALUES (%s, %s, %s, %s, %s, %s, now()", (file_name, file_size, date_accessed_epoch, date_modified_epoch, date_changed_epoch, ext))

def checkForDeleted(path, cursor):
    cursor.execute("SELECT MAX(id) WHERE fs_monitor GROUP BY file_name")
    file_ids = cursor.fetchall()
    for id in file_ids:
        cursor.execute("SELECT file_name, deleted FROM fs_monitor WHERE id=%s", (id,))
        row = cursor.fetchone()
        if row[1] == "FALSE":
            checkFile = path+"/"+row[0]
            if not os.path.exists(checkFile):
                cursor.execute("INSERT INTO fs_monitor (file_name, deleted, added_to_database) VALUES (%s, 'TRUE', now())", (row[0],))


cnx = connect_to_database()
cursor = cnx.cursor(buffered=True)

path = "*******"

initialPathLength = path.__len__()
cursor.execute("INSERT INTO python_run (status, monitor_type, run_time) VALUES ('started', 'fs', now())")
checkMonitorRecords(file, path, initialPathLength, cursor)
cursor.execute("INSERT INTO python_run (status, monitor_type, run_time) VALUES ('deleted check done', 'fs', now())")
for (path, dirs, files) in os.walk(path):
    if files:
        for file in files:
```

```
            checkMonitorRecords(file, path, initialPathLength, cursor)

cursor.execute("INSERT INTO python_run (status, monitor_type, run_time) VALUES
    ('finished', 'fs', now())")

cnx.close()
```

B.5 Example Analysis Code

Provided here is an example piece of analysis code to produce the PartBook network (Figure 10.3b).

```
import core_functions
import matplotlib.pyplot as plt
import numpy as np
import networkx as nx

def artefactPeopleNetwork(cursor):
    artefacts = ['21','24','39','61','29','72','85','44','66','84']
    cursor.execute('SELECT ipk_ID FROM IPK WHERE artefact_ID IN
        (21,24,39,61,29,72,85,44,66,84)')
    comms = cursor.fetchall()
    commString = "("
    for comm in comms:
        commString += str(comm[0])+","
    commString = commString[:-1]+")"
    print commString

    cursor.execute('SELECT DISTINCT(hashUserID) FROM conversation WHERE ipk_ID
        IN '+commString)
    engineers = cursor.fetchall()
    artefactEngineerMatrix = np.zeros((len(artefacts),len(engineers)))

    for i, artefact in enumerate(artefacts):

        cursor.execute('SELECT ipk_ID FROM IPK WHERE artefact_ID='+artefact)
        comms = cursor.fetchall()
        queryString = "("
        for comm in comms:
            queryString += str(comm[0])+","
        queryString = queryString[:-1]+")"
        print commString

        for j, engineer in enumerate(engineers):
            cursor.execute('SELECT COUNT(*) FROM IPK WHERE hashUserID=%s AND
                ipk_ID IN '+queryString, (str(engineer[0]),))
            count = cursor.fetchone()
            print count
            artefactEngineerMatrix[i,j] = count[0]

    print artefactEngineerMatrix
    G = nx.Graph()
    for i, artefact in enumerate(artefacts):
        G.add_node(i, type='artefact', id=artefact)
    for j, engineer in enumerate(engineers):
```

```
        G.add_node(j+len(artefacts), type='engineer', id=engineer[0])

    for i, artefact in enumerate(artefacts):
        for j, engineer in enumerate(engineers):
            if artefactEngineerMatrix[i,j] > 0:
                G.add_edge(i, j+len(artefacts), weight=artefactEngineerMatrix[i,
                    j])

    nx.write_gexf(G, '*******')
    nx.draw(G)
    plt.show()

def people_network(cursor):
    cursor.execute("SELECT hashUserID FROM users")
    users = cursor.fetchall()
    userSet = []
    for user in users:
        userSet.append(user[0])
    cursor.execute("SELECT ipk_ID FROM IPK")
    ipkIds = cursor.fetchall()
    userMatrix = np.zeros((len(userSet),len(userSet)))
    for id in ipkIds:
        cursor.execute("SELECT hashUserID FROM conversation WHERE ipk_ID=%s AND
            hashUserID!='' ", (str(id[0]),))
        hashIds = cursor.fetchall()
        #print hashIds
        if len(hashIds) > 0:
            for i in range(len(hashIds)-1):
                for j in range(len(hashIds)):
                    if hashIds[i][0] != hashIds[j][0]:
                        x = userSet.index(hashIds[i][0])
                        y = userSet.index(hashIds[j][0])
                        userMatrix[x,y] = userMatrix[x,y] + 1
    print userMatrix
    diagMatrix = np.zeros((len(userSet),len(userSet)))
    for i in range(len(diagMatrix)):
        for j in range(i,len(diagMatrix)):
            diagMatrix[i][j] = userMatrix[i][j] + userMatrix[j][i]
    print diagMatrix
    G = nx.Graph()
    for i, user in enumerate(userSet):
        G.add_node(i, userId=user)
    for i in range(len(diagMatrix)):
        for j in range(i,len(diagMatrix)):
            if diagMatrix[i][j] > 0:
                G.add_edge(i,j, weight=diagMatrix[i][j])

    nx.write_gexf(G, '*******')
    nx.draw(G)
    plt.show()


print "Connecting to the Database"
cnx = core_functions.connect_to_database('*******')
cursor = cnx.cursor(buffered=True)

```

```
people_network(cursor)

cnx.close()
print "Script Finished"
```

Appendix C

Publication Abstracts

This appendix contains the publications alongside their abstract, which have been produced by this research.

A Social Media Framework to Support Engineering Design Communication

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

Journal of Advanced Engineering Informatics
2013

Abstract

Engineering Design Communication (EDC) is fundamental to almost all Engineering Design activities as it provides the ability for knowledge and information to be shared between engineers. It is part of 'what we do'. This communication contains a great deal of rationale relating to the evolution of Product Development and is essential for understanding 'why the product is the way it is'. The need to support EDC is becoming more important due to the fact that Product Development is becoming more distributed, multi-disciplinary and involving greater re-use of past designs. With the advent of Social Media (SM), it is argued that there is the technical capability to provide more effective support for EDC within a computer-mediated environment. In order to explore this potential, this paper defines the requirements for the effective support of EDC through an extensive review of the literature. It then discusses the suitability of a SM approach and then presents the theoretical foundations of a SM framework to support EDC.

An Exploratory Study into Advanced Real-Time Categorisation of Engineering E-Mails

James A. Gopsill, Steve J. Payne & Ben J. Hicks

IEEE International Conference on Systems, Man and Cybernetics, SMC
Manchester, United Kingdom, 2013

Abstract

For large, spatially and temporally distributed engineering projects, e-mail is a central means for the discussion of engineering work and sharing of digital assets that define the product and its production process. The importance of communication and the value of its content for resolving issues *post facto* are universally accepted. More recently, the potential value of its content to predict events, issues and states *a priori* has been explored with some success. However, while in the former context (*post facto*) trends and patterns can be established through iteration and refinement over time; for prediction, heuristics need to be established in advance and closer to real-time analysis becomes necessary due to the critical and very often short timescales. It is this challenge of making predictions from the content of e-mail that is considered in this paper. In particular, the paper deals with engineering e-mail and the ability to automatically predict its purpose from its content rather than relying solely on the subject line.

The work builds upon previous studies by the authors concerning the characterisation of the content of e-mail: what they are about, why they were sent and how the content is expressed. The paper summarises the previous work and looks at the potential of identifying the purpose of e-mail through the use of Naive Bayes and an adapted Latent Semantic Analysis approach. While the techniques have only been applied to an initial exploratory study of 98 e-mails, the results suggest the potential for automated real-time categorisation of engineering e-mails through achieving an accuracy of 66%. Such a capability would both support prioritisation of e-mail for engineers and macro level characterisation of project e-mail dynamics. The latter provides the opportunity for real-time analysis of an engineering projects status and correspondingly, modes of management intervention.

Meeting the Requirements for Supporting Engineering Design Communication - PartBook

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

International Conference on Engineering Design, ICED
Seoul, South Korea, 2013

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.

The Communication Patterns of Engineers within SME in 2013

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

International Conference on Engineering Design, ICED
Seoul, South Korea, 2013

Abstract

The communication patterns of engineers has been well researched over the past decades. However, due to the rise of new communication technologies and their speed of inception within society, it can be argued that this research could be less relevant to modern communication patterns of engineers. In addition, the engineers may have a preference on the communication technology used depending on the subject or purpose of the communication. Therefore, this paper discusses the results from an exploratory study that has investigated the communication patterns of engineers within an SME in 2012. The instances of communication, subject of communication and the purpose of communication were of particular focus. From this, a list of subjects and purposes for the communications was generated, which engineers were able to assign their communication to.

PartBook - A Social Media Approach for Capturing Informal Product Knowledge

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

DESIGN
Cavtat, Croatia, 2012

Abstract

There is a gap within the current capability of engineering companies' information system infrastructure where there is no system that currently captures, manages and shares the full scope of informal engineering communication. This paper presents an overview of the research being undertaken to create a social media tool for the capture, management and sharing of informal engineering communications. The focus of the paper is on the social media approach bring taken and demonstrator system being used to evaluate and validate the underlying framework.

Learning from the Lifecycle: The Capabilities and Limitations of Current Product Lifecycle Practice and Systems

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

International Conference on Engineering Design, ICED
Copenhagen, Denmark, 2011

Abstract

Design teams within the High Value Low Volume (HVLV) industry are facing ever-increasing challenges in developing new products. This has been largely due to the paradigm shift towards Product Service Systems, the growing importance of demonstrating Corporate Social Responsibility and stricter environmental legislation. With the variant nature of the design process within the HVLV industry and the longevity of the product life-cycles, it is recognised that learning from previous products is essential for new product innovation and development. The ability to do this depends upon the companys product lifecycle practice and systems, and its inherent capability/limitations. To explore these issues, this paper maps typical data and information flow and the Information Systems involved, onto a generalised product lifecycle for HVLV. The map is generated from an extensive literature review and is used to critically appraise and reflect upon current product data lifecycle practice. In particular, its capability to provide design teams in the HVLV industries with sufficient data and information throughout the lifecycle phases of existing products to inform variant product design is considered.

Trends in Technology and their Possible Implications on PLM: Looking Towards 2020

James A. Gopsill, Hamish C. McAlpine & Ben J. Hicks

International Conference on Product Lifecycle Management, PLM
Eindhoven, Netherlands , 2011

Abstract

Engineering companies within the High Value Low Volume (HVLV) industry are facing ever-increasing challenges due to the shift towards Product Service Systems (PSSs), and the inclusion of Corporate Social Responsibilities (CSRs) and environmental legislation into their business strategy. Addressing these challenges requires a fundamental understanding of data and information across the entire Product Lifecycle and there is a concern as to whether the current systems for capturing and managing data and information across the product lifecycle can provide the learning and knowledge necessary.

To begin to understand this concern, the paper explores the current state-of-the-art research in applying Knowledge Discovery and discusses their capabilities and limitations with respect to the product lifecycle. The paper then looks towards 2020 and considers emerging ICT technologies and their possible implications on PLM.