A SYSTEMATIC TECHNOLOGY EVALUATION AND SELECTION METHOD FOR COMPUTER-SUPPORTED COLLABORATIVE DESIGN.

By Ross Brisco.

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Ross Brisco

Department of Design, Manufacturing and Engineering Management
Faculty of Engineering
University of Strathclyde
Glasgow, UK

This dissertation is submitted for the degree of Doctor of Philosophy

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DECLARATION OF AUTHENTICITY AND AUTHOR'S RIGHTS

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination, which has led to the award of a degree.

Signed: Ross Brisco

Date: 1/6/21

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I would like to make particular thanks to those who have supported me in the journey to achieve my PhD

I would like to thank my supervisors Ian Whitfield and Hilary Grierson who have guided me in my journey to become an academic and have become close friends. My achievements over the years would not be possible without their support.

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PREVIOUSLY PUBLISHED WORK

This thesis consists, in part, of previously published work related to this research project. Where specific text, figures and tables are used, they are referenced. Appendix 1 contains letters from the publisher of the following publications, allowing the work within this thesis, including all figures and tables.

During this research project the academic outputs were: one journal article, six conference papers and three conference workshops.

Journal Article

Research in Engineering Design (2019)
A novel systematic method to evaluate computer-supported collaborative design technologies.
Ross Brisco, Robert Ian Whitfield, Hilary Grierson

Conference Papers

E&PDE (2020)

Developing an online course in Computer-Supported Collaborative Design (CSCD)

Ross Brisco, Robert Ian Whitfield, Hilary Grierson, Bryan Howell, Cameron Unson, Carly Matheson

Paper presented at the 22nd International Conference on Engineering and Product Design Education, Herning, Denmark.

E&PDE (2019)

Overcoming the challenges of global collaboration through design education

Ross Brisco, Robert Ian Whitfield, Hilary Grierson, Erik Bohemia

Paper presented at the 21st International Conference on Engineering and Product Design Education, Glasgow, United Kingdom.

E&PDE (2018)

Are social network sites the future of engineering design education?

Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.

Paper presented at the 20th International Conference on Engineering and Product Design Education, London, United Kingdom.

DESIGN (2018)

Modelling the relationship between design activity and computer-supported collaborative design factors.

Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.

Paper presented at the 15th International Design Conference, Dubrovnik, Croatia.

ICED (2017)

The use of social network sites in a global engineering design project.

Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.

Paper presented at the 21st International Conference on Engineering Design, Vancouver, Canada.

E&PDE (2016)

Recommendations for the use of social network sites and mobile devices in a collaborative engineering design project.

Brisco, Ross; Whitfield, Robert; Grierson, Hilary.

Paper presented at the 18th International Conference on Engineering & Product Design Education, Aalborg, Denmark.

Conference Workshops

Design (2018)

Mapping success in collaborative engineering.

Brisco, Ross; Whitfield, Robert Ian; Evans, Dorothy.

Workshop delivered as part of the 15th International Design Conference, Dubrovnik, Croatia.

In association with the Collaborative Design Special SIG, The Design Society.

ICED (2017)

Collaborative Design Education.

Brisco, Ross; Howell, Bryan; Whitfield, Robert Ian; Evans, Dorothy; Thomson, Avril; Ion Willian.

Workshop delivered as part of the 21st International Conference on Engineering Design, Vancouver, Canada.

In association with the Collaborative Design SIG & The Design Education SIG, The Design Society.

EPDE (2016)

How can social network sites support collaboration within product design education?

Brisco, Ross; Whitfield, Robert Ian; Evans, Dorothy; Fahnenmüller, Lennart.

Workshop delivered as part of the 18th International Conference on Engineering & Product Design Education, Aalborg, Denmark.

In association with the Collaborative Design SIG, The Design Society.

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STUDENT ENGAGEMENT

This thesis includes work conducted with the following groups. Outcomes from each of these engagements are described throughout, and reference is made to each individual group as a source, development or analysis of knowledge. Ethics approval was sought and approved by the Department of Design, Manufacturing and Engineering Management ethics committee at the University of Strathclyde with no concerns.

Global Design Project (2015 - 2020)

- In-class Tutor and lecturer (2015-2019) to University of Strathclyde students.
- Collaborative Design Workshop (2016-2018) delivered to University of Strathclyde students.
- Computer-Supported Collaborative Design online short course (2019 & 2020), delivered to students of the University of Strathclyde, University of Canterbury, University of Malta, Turku University of Applied Sciences.

The Global Studio (2016 & 2017)

- Invited Guest Lecturer for University of Loughborough students.
- Collaborative Design Workshop, at the University of Loughborough.

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ABSTRACT

Design is a global activity. It requires collaboration between individuals across borders and beyond barriers. Modern global design is achieved using computer technologies that support many activities of a design process. However, merely supporting design does not guarantee that it is a successful endeavour. The requirements of computer-supported collaborative design are abstract. They are influenced by human-to-human interaction and/or human to computer interaction. As our society moves towards faster communication technologies and a higher number of collaborative technologies available, the need to evaluate the available tools and select the best tool at the appropriate time of the design process is becoming more compelling. If the best tools are not identified, there are missed opportunities for productivity, impacting team communication, cooperation, coordination, and collaboration.

Student designers at University have experienced an observable change in technology use within their personal and academic lives. The proliferation of Web 2.0 technologies and the spread of social media, social network sites and mobile technologies have impacted how students socialise and engage in group project work. However, it is unclear if these technologies support or hinder the design process. This behaviour change has led to a motivation to understand the use of technologies to support Computer-Supported Collaborative Design teamwork.

This research intended to support Computer-Supported Collaborative Design teamwork by defining the requirements of Computer-Supported Collaborative Design, the technologies which can be used to support Computer-Supported Collaborative Design, the technology functionalities which these technologies feature, and to use this knowledge to systematically evaluate and select the appropriate technology to use for any given collaborative situation.

The outcomes of this research documented within this thesis became the development of a systematic and automated method to allow engineering design teams to evaluate technologies based on the existing knowledge of the requirements of Computer-Supported Collaborative Design and select which technologies would best support their group design activities. This technology evaluation and selection method was achieved by the creation of the Computer-Supported Collaborative Design matrix, a tool which enables the evaluation of technologies against Computer-Supported Collaborative Design requirements; the creation of an auto-population method for the tool supporting

consistency and efficiency of using the method; and the development of an education programme to ensure the correct use of the Computer-Supported Collaborative Design matrix.

The Computer-Supported Collaborative Design matrix can be used to support the assessment and selection of technology for use in Computer-Supported Collaborative Design projects by engineering design teams in an educational environment. The tool has been evaluated through demonstration of use for a class and implementation within a class environment. Beyond the Computer-Supported Collaborative Design matrix as a tool, a robust and systematic method of creating the tool has been documented, which is the first step towards broader use of the tool.

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LIST OF ABBREVIATIONS

Abbreviation	Full form
AKA	Also Known As
AR	Augmented Reality
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CPD	Continuous Professions Development
CSCD	Computer-Supported Collaborative Design
F2F	Face to Face
GDP	Global Design Project
HoQ	House of Quality
KM	Knowledge Management
LMS	Learning Management System
NPD	New Product Development
PBL	Problem/Project-Based Learning
PD	Product Design
QFD	Quality Function Deployment
SME	Small and Medium Enterprise
SNS	Social Network Sites
TMG	Team Management Groupware

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1 INTRODUCTION

This thesis details research in the development of a technology evaluation and selection method to support Computer-Supported Collaborative Design (CSCD) teamwork. The technology evaluation and selection method created involved the development of a framework named the CSCD matrix which utilised the knowledge of the requirements of CSCD and the knowledge of the technologies that are used to support CSCD and the functionalities that these technologies have to enable team collaboration. To support the use of the evaluation and selection method, data was collected and coded to automatically populate the CSCD matrix. The automatic population method supports a systematic population of the matrix which reduces the time and knowledge required to populate. This method required the development of a coding schema agreed on by three researchers, the production of three dictionaries of synonyms, and the creation of software code to apply rules, based on the dictionaries, to the data collected.

This method was created within an educational context, and the outcomes of this research contribute towards future education with the creation of an online short course supporting an understanding of the requirements of CSCD and the use of the CSCD matrix. The value of the method is demonstrated using a case study of the Global Design Projects (GDP).

Within this chapter, foundational knowledge on the research area is presented to define the boundaries of the research. State-of-the-art knowledge is used to introduce the motivation for the research and to justify the significance of filling a gap in knowledge for engineers.

1.1 What is Computer-Supported Collaborative Design

As internet technology continues to improve, the support that computer technology can offer is ever-changing and increasing in functional possibilities. Computer-Supported Collaborative Design (CSCD) is an area of research that investigates collaboration between designers using computer-based technologies to perform collaborative design activities. Within this context, this research will examine the current state of the CSCD research field, recent changes in technology that supports CSCD, changes in human behaviour, and the opportunities to fill gaps in knowledge to support the collaboration of design teams.

The field of CSCD research dates back to the 1960s with the development of computers and internet technology to facilitate distributed business communication (Johansen 1988). Whilst this software was only sophisticated enough to facilitate text communication, the technology landscape quickly developed the capabilities to transfer images, audio and video. Modern technologies use these basic functionalities to enable everyday communication such as email, video conferencing, cloud storage systems and instant messaging; or more tailored technologies including Computer-Aided Design (CAD), Product Data Management (PDM), Cave Automatic Virtual Environment (CAVE) environments, digital whiteboards, groupware systems and knowledge management systems (Hsu 2013; Borsato et al. 2015; Shen et al. 2015). Whilst these technologies are not specific to CSCD, they are utilised to support CSCD.

These technologies provide innovative methods of communication, cooperation and coordination within an engineering design context with the potential to foster greater collaboration for internal teams, external collaborators and across boundaries (Hicks 2013; Sarka et al. 2014).

Collaboration is a distinctly different mode of working from similar terms of coordination and cooperation. It is commonly understood and agreed that coordination is a distinctive activity focusing on "planning, scheduling, representation, decision making and control of product development" (Duffy 2002). However, the significance of the difference between the terms cooperation and collaboration was somewhat contested. Several academics have argued that cooperation and collaboration are not distinct enough, and many academics use the terms interchangeably. This confusion may be due to ignorance in terminology, cultural differences or native language translation.

Collaboration can be defined as having a higher level of complexity than cooperation because it involves shared risk of failure and opportunities for shared success (Adams 2015). Collaboration is mutually beneficial and requires a common goal somewhere in the process towards a shared outcome, whereas cooperation differs: requiring the sharing of knowledge and resources towards a shared activity with no requirement for a shared goal (Kvan 2000). When barriers of communication, cooperation and coordination can be overcome, they contribute towards successful collaboration (Kock 2007).

The number of technologies that support CSCD is ever increasing, with new functionalities emerging utilising innovative interfaces. Virtual reality, augmented reality technologies, and telepresence robotics are emerging areas in research that can be utilised to support innovative, collaborative design activities (Ahram et al. 2011). And with increasing functionalities of technologies, the practical utilisation of these technologies is ever-changing.

Novel functionalities which support CSCD include; multi-threaded conversing for the tasks of creating or replying to a comment; tagging, which enables increased awareness of discourse amongst team members and liking, which allows encouragement of and is a way to measure agreement towards decision making (Gopsill 2014); document versioning control; sharing and computer-based coordination systems (Brisco et al. 2016). This new functionality has the potential to improve teamwork (Zhao & Rosson 2009), enabling the essential functionalities required by professional design teams (Mamo et al. 2015) and any advances in functionality have the potential to change the way future workers will collaborate (Brisco et al. 2018).

1.2 Supporting CSCD

CSCD can offer a better medium for collaborative design work. As Gopsill (2014) suggested, novel social technologies can "provide a more collaborative method of communication" for engineering design teams. Bringing people together in virtual environments has obvious business benefits improving collaboration resulting in reduced costs and faster development (Jassawalla & Sashittal 2006).

Brewer (2015) proposes that the success of global virtual collaboration is not measured in typical business metrics and instead by the relationship and how well it was managed. This is an aspect that is much more difficult to define.

However, this is not to say technology can or should replace face-to-face co-located working as this cannot be proven for all contexts (Hatem et al. 2012). The requirements of the collaborative activity(ies) and team membership characteristics are just two factors that can have a significant influence. Törlind & Larsson (2002) stated: "The highly informal, accidental, spontaneous communication that characterises everyday work has an impact on a design that sometimes is even greater than that of formal communication". This 'watercooler moment' offers employees an opportunity to socialise and discuss work informally; however, the technologies which support CSCD have always had a difficulty mimicking the phenomenon in the same way.

To support a full range of design activities and CSCD possibilities, typically, a range of technologies is employed, such as a toolkit (Mamo et al. 2015). Mamo proposed the technologies to support a global design project as a toolkit based upon observations of a class with students who acted as distributed design team members and the typical tools used by students to facilitate their distributed collaborative design project work. It is not only important to identify the tools of a toolkit, but to select appropriate tools for the entire design project or a specific design activity.

Appropriate technology selection has been demonstrated to improve both technology capacity and technology management capacity, which in turn increases innovation performance (Hao et al. 2007), supporting both business and socio-technical interests. When successfully conducted, a selection of technology has the potential to minimise risks, increase awareness for the project manager and other management teams, resulting in increased performance and affecting project objectives (Rassias and Kirytopoulos 2014).

Torkkeli and Tuominen (2002) reflected, "A company can waste its competitive advantage by investing in wrong alternatives at the wrong time or by investing too much in the right ones. It is more and more difficult to clarify the right technology alternatives because the number of technologies is increasing, and technologies are becoming more and more complex".

Problems can arise with technology selection when one technology offers the same functionality as another, either causing redundancy of functionality or confusion over which technology should be used (Brisco et al. 2017). This supports the need for an assessment of the technologies which are selected to support design activities and the overall design process. Boyd and Ellison (2007), suggested that one of these problems is in the terminology used; "the nature and nomenclature of these connections may vary from site to site", suggesting that there is some complexity in defining the functionality of a technology and abilities of a functionality which makes comparison difficult.

It is not a trivial task to choose CSCD Technology. Cross (2014) surmised, "… they [companies] may dive into using it [technologies] without forethought or proper risk assessment. On the other end of the spectrum, it may be treated as bleeding-edge technology that is largely untried, untested, and/or poses a substantial threat".

To conduct a successful technology selection, there has to be an understanding of the technology functionality and how this satisfies the requirements of the project work. And often, the person or team employed to make this decision does not have all the appropriate information (Sivunen & Valo 2006). If inadequate technologies are selected, which add additional complexities such as a greater number of technologies to fill the gaps in functionality or complex team protocols for managing the sharing of information (Sclater 2008). There are also the issues of protecting interests as part of using technology such as assets, copyrighted materials and other intellectual property (Cross 2014).

1.3 The motivation for this research

The motivation for this research resulted from an observed change in student behaviour, particularly as part of the Global Design Project (GDP), a class at the University of Strathclyde.

In 2015 observations were made of students' behaviour within the GDP class, choosing to use social network sites and mobile devices to communicate with distributed team members from other partner Universities located in London and Malta. This practice appeared to be successful in facilitating communication between team members and supported collaboration when conducting digital design activities. To establish if this was the case, a research investigation was required.

The GDP has been in its current form since 2006. The class employs joint lectures hosted by the participating institutions from multidisciplinary backgrounds. Each team acts as a distributed design group that collaborates to design a product and deliver a distributed presentation. The projects provide students with the experience of global collaborative design and the opportunity to reflect on the benefits and barriers of this mode of collaboration. There are typically 50 students per year across all institutions split into around eight teams. Many institutions have participated in the projects, including recently, City University London, University of Malta, University of Mostar, Budapest University of Technology, University of Canterbury, Turku University of applied sciences and the University of Strathclyde.

In previous years of the class, technologies were used for communication such as email, wiki pages and forums, and powerful devices such as laptop and desktop computers were required. This observed change towards using social network sites and other social software such as (instant) messengers, enabled devices like smartphones to be used by students as a primary computing and communication device.

Social network sites are a category of social media (Lietsala and Sirkkunen, 2010), and the two should not be confused. Users can share content, converse and conduct everyday tasks such as organising events. Social network sites generally have Web 2.0 functionalities enabling easy sharing, but the specific functionalities change from website to website (Brisco et al. 2017). Social network sites can be classified as social software and are sometimes used in enterprise as 'groupware' if they include social functionalities.

The change in the technology used to communicate and conduct collaborative activities, and the change towards mobile devices appeared to support teamwork. Certain teams reported fewer inter-team issues when using particular technologies (Brisco et al. 2016), and by delivering guidance on technology selection based on what was known at the time within the literature, and experiences from previous iterations of the class, team collaboration issues were reduced (Brisco et al. 2017).

This observation was not unique to the GDP. Students' behavioural changes in the use of technology had been documented in the literature around this time (Pektaş 2015; Gopsill et al. 2015; Mamo et al. 2015; Knutas et al. 2013; Klimova 2016; Hurn 2012; Johri et al. 2014; Lippert et al. 2017) with the addition of other technologies, usually video conference and cloud storage. Mamo et al. (2015) commented: "social networks have become increasingly popular with students […] for their ease of use, ubiquity and students familiarity with the systems." Currently students are dictating how they conduct projects based on their own perception of the functionality provided, and the requirements of their global collaborative work. This is not based on academic understanding, and does not reflect the dynamic nature of technology use in collaborative projects.

Prior to the 2015 GDP class, the standard practice was to give students access to a document of potential technologies they might use which was created in 2012. As this document was created many years before, considering the speed at which technology changes, some of the technologies which were listed were no longer available, or did not perform the same functionality as reported. This list of potential technologies was intended to encourage students to explore otherwise unidentified technologies. However, when they discovered that the technologies were no longer available, they resorted to using technologies which they were familiar with or had experience with for social communication or previous university work.

On reflection of the experiences of technology use within engineering design education, there was a desire to deliver the students of the GDP with a guided method to evaluate and select technology for use within their projects. In addition, the same observation of a behavioural change was across design literature in different contexts. The GDP was a suitable vehicle to realise the research as practically the research had access to the class and could utilise the outcomes that students produced. The researcher could formally and informally learn about the students actions within the projects on a weekly basis. Additionally, the students were engaging in a computer-supported collaborative design project required for the research focus.

There was no known method to systematically evaluate the available technologies against the collaborative requirements of the projects. If this method were to be used in subsequent generations of the class, it should ideally be easily updatable through automation, and as the speed of technology development and change is high, the method must be quickly adapted.

The Global design project is not the only class that would benefit from such a method. The European Global Product Realisation (EGPR) aimed to teach "engineering students professional knowledge and practical skills of new product development in a geographically dispersed and virtual environment" (Vukasinovic et al. 2017). The course took place annually from 2002 and usually has between 30-50 students each year. Research within the course demonstrated the importance of employing a partly collocated, and partly virtual, environment for students to collaborate (Vidovics et al. 2016) and the development of a teaching methodology (Kovacevic et al. 2017).

The Global Studio is another programme that has been jointly organised between several international Universities and commercial partners annually since 2006. The class delivers a mixture of project-based learning circumstances to students alongside taught classes on state-of-the-art theories of global design. The class is different from the others mentioned in providing students with the experience of having the position of both the client and design team for a complete appreciation of the complexities of global collaborative design.

To support any of the classes mentioned within this chapter, or any other distributed design class, there is a need to understand the requirements of support and to plan the implementation. Within an educational environment, this involves the teaching of a potentially new method of conducting CSCD in a practical way, supporting students' project development.

There are two theories of engineering education, the behavioural model and the constructionist model (Emami 2009), both reflect well-held world views. The behavioural model assumes that knowledge passed on, for example, from a person to a person, a book to a person, a video to a person etc. The constructionist model assumes knowledge is created in the mind of the learner based on outside stimuli. For example, within a team discussion, one idea might stimulate the idea of another person based on the interpretation of the idea. The constructionist model is representative of Problem/Project-based learning (PBL) and reflection activities after learning has taken place (Yang 2010). Emami (2009) highlighted a trend in engineering education towards the constructionist learning model and how this model supports many team-based engineering activities, including team communication, trust and skills building.

To develop skills in digital literacy, students must experience digital technologies within a safe and educational environment, as identified by Bohemia & Ghassan (2012), who stated: "We propose that the proliferation of Web 2.0 technologies and their incorporation into the learning and teaching environment means that academic staff and students will need to develop skills in digital literacy to participate effectively in distributed project-based collaborative work". These skills can be developed in an educational context to benefit future workers as identified by Gopsill (2014) "If the benefits of technology skill-building could be better understood and communicated to students the next generation of workers will be in a better position to adapt to a modern, agile and dynamic workplace."

There is criticism of learning technology research as highlighted by Beetham & Sharpe (2013), who stated: "Teachers who are excited about these technologies are often accused of using them regardless of whether or not they are pedagogically effective, and even in ignorance of the long tradition or pedagogical evidence thought." If state-of-the-art practices can be identified and implemented within a classroom activity, students will have the experience of building skills in these areas, which are relevant to current practices. One issue is that although there is much published in the literature, it does not make its way back into the classroom due to a lack of awareness or time constraints of the educators (Brisco et al. 2018). By empowering students with knowledge from literature, tried and tested methods, and the ability to experiment with technologies will position these students with the ability to make informed decisions on their technology selection.

The research conducted within this thesis sits within a context. There was an observed change in student behaviour and a desire to investigate this. There was a need to provide a contribution to research, as required to achieve a PhD, but also a contribution to education to solve the problems experienced by global projects classes. The experience of the GDP influenced the aim of the research and vice versa until a suitable project for both was found, research conducted and a solution established and evaluated.

Although studies in an educational context, lessons learned in conducting and producing the research has the potential to impact industry in an understanding of CSCD within particular sectors. The development of a CPD in strategic technology selection for CSCD is a future impact with the potential to deliver post pandemic resilience. Within education, other global projects can easily adapt the shot online course and lessons from the method into their modules.

When this research began in 2015, it was unimaginable that a method for the evaluation and selection of technology would become so valuable to the design community. COVID-19 and the “work from home” restrictions that have been in place since early 2020. Where physical collaboration was the primary or preferred method for many, this is not possible, and online collaboration has become the necessary mode.

This research is needed now more than ever. Going beyond global design and distributed design. We now find ourselves as a human race, not with a desire to collaborate using computers, or with a requirement to collaborate using computers, but it is now a necessity. We cannot perform these collaborative tasks without them. In many ways, a paradigm shift has occurred. Pre-pandemic research was focused on technologies to support distributed work as a novel concept, as secondary to in-person working. Now, research must consider remote working as the default or as equal. Solutions must allow those who have the knowledge to participate at the right time in a project, and so they must be able to join in person or digitally.

Whilst there has been an interest towards nomadic/remote working in engineering research (Gutierrez et al. 2013; Gutierrez et al. 2013; Shklovski et al. 2015; Vodanovich et al. 2010), even for those who could practically be operating from the same office, this was uncommon. “Work from home” mandates for those who can, have empowered workers and businesses to experience the alternative. Many workers and businesses are optimistic about the opportunities of remote working and hot-desking which can offer improvements in health, reduce overheads, and the potential to reduce gender/race imbalance (Bick et al. 2020).

1.4 Thesis structure

This thesis is structured to logically convey the research undertaken and to justify how each step has contributed towards the motivation. Every chapter will begin by summarising relevant outcomes from previous chapters and introducing the purpose of the current chapter. The sections are developed as unique unifying themes, whilst each of the chapters has a broader purpose.

Chapter 2 details the preliminary investigation into the motivation for the research. A survey was conducted to better understand the change in student behaviour observed in the GDP towards novel technologies such as social network sites. From this, a further survey is described to determine the technologies commonly used by students and how technologies have changed over time. Finally, the methods of supporting students in technology evaluation and selection were explored from the published literature and lessons from successful methods are discussed. This chapter justifies the motivation behind the research through preliminary studies and determines that there is a need to develop a systematic automated method to allow engineering design teams to evaluate and select suitable technologies to support CSCD. This chapter concludes by defining the aims and objectives of the research and research questions.

Chapter 3 describes the research approach adopted by the author based upon their understanding of research philosophy and the defining concepts of paradigm, ontology, epistemology and methodology. The world view is presented and the assumptions made are rationalised to determine how the outcomes of this research are understood. This chapter is essential to define why decisions were made towards the selected research approach. This chapter concludes with the research approach map, which details all sources of knowledge (relevant to the world view selected), all knowledge-building activities and all contributions to knowledge.

Chapter 4 presents the literature search and review with the purpose of identifying the gap in knowledge by situating the research within the context of the current literature and to build upon the existing research work. This chapter presents the literature search procedures conducted before discussing the literature found in three areas; the requirements of CSCD, the technologies that can be used to conduct CSCD and the functionalities of technologies that satisfy the requirements of CSCD. To fill the gap in knowledge, there is a need to build upon the existing research.

Chapter 5 details the research activities conducted to identify the requirements of CSCD. First, the requirements of CSCD found in the literature were extracted and categorised using an established categorisation of collaborative design. With the knowledge of experts in CSCD, the initial categorisation was updated and verified. Workshops took place to develop requirements of CSCD. These new lists were compared with the existing list created from the literature. Few changes were found but whenever the categorisation was changed the reasons are discussed. The requirements of CSCD were aligned with the categories and sub-categories to enable the creation of 19 CSCD requirements statements that were further verified using a questionnaire. Experts provided feedback on each of the requirements statement, and changes were made as required.

Chapter 6.1 & 6.2 introduces the CSCD matrix and a justification of the logic in its creation is provided based upon the motivation, research approach and outcomes of the literature search. The E2 design activity model with CSCD factors is used as a justification for the factors that influence CSCD and how they impact design activities. These factors can be positive or negative and can be human or technological in nature. To meet CSCD requirements, these factors must have a positive influence on the design activity. The completed CSCD matrix is presented in this chapter, with the requirements and technology functionalities populated. The requirements are derived in Chapter 5, and the list of technology functionalities is described in Chapter 2 from the literature and evaluated and selected based upon outcomes from the literature review (Chapter 4). Technologies were evaluated, and it was decided that they are specific to individual CSCD projects and were not included in the CSCD matrix template. The challenges of populating the CSCD matrix in a design team are discussed before an automated approach is detailed.

Chapter 6.3 details the creation of a data coding and automatic population method for the CSCD matrix. Data was collected from the GDP in 2015, 2016, 2017 and 2018 on the use of technologies that support CSCD. Data was collected from informal interviews with students of the class, recorded in a class diary. Data was also collected from student reports on their use of technologies within the projects. This data was used to create a coding schema with three coders experienced in CSCD. The outcomes of the coding were used to create semantic dictionaries of terms used to describe the requirements of CSCD, the technologies used in CSCD and the functionalities of technologies for CSCD.

Chapter 6.4 & 6.5 demonstrates the use of the three dictionaries to create a method to automatically populate the CSCD matrix. GDP data collected 2018, and data science software was used to enable the coding of the data. The software was programmed to the logic of the CSCD matrix and the dictionaries to reveal the connections between technologies, technology functionalities and requirements of CSCD. The software exports the data links and a confidence score to a spreadsheet which was used to populate the CSCD matrix template automatically based upon the processed data.

Chapter 7 discusses the outcomes of the method for the GDP 2018. Multiple confidence levels were produced as enabled by the method. The outcomes of the data are discussed, and differences between the confidence levels reveal the nature of technology support for CSCD to meet the requirements. This chapter acts as a demonstration of the outcome of the CSCD matrix and automated population method. The outcomes demonstrate how the method can be used to evaluate and select suitable technology.

Chapter 8 provides a discussion of the findings from the development of the CSCD matrix and the systematic method to populate the CSCD matrix. The implications of the contributions to knowledge are discussed, with a focus on an educational setting. The development of the CSCD matrix within an enterprise setting are discussed in the context of future work.

Chapter 9 concludes the thesis summarising the research, followed by the list of references list and appendices.

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2 PRELIMINARY INVESTIGATION TO ESTABLISH AIMS, OBJECTIVES AND RESEARCH QUESTIONS

This chapter presents the preliminary research conducted to investigate the change in student's behaviour regarding their technology use during the Global Design Project. Chapter 1 introduced the GDP and detailed the motivation to investigate a change in student behaviour in using novel technologies such as Social Network Sites (SNS) to conduct distributed CSCD projects. The research within this chapter investigates the technologies used in the GDP and the attitudes towards novel technologies. The chapter concludes with the aims, objectives and research questions that define the research.

The preliminary investigation includes students of the Global Design Project (GDP) at the University of Strathclyde and students of the Global Studio (GS) class at the University of Loughborough.

Studies in the GDP include: a survey of students in 2016 on attitudes towards the use of SNS, a survey of students uses of technologies for personal communication and for GDP communication in 2015, 2016, 2017 and 2018, and a workshop asking students to identify the challenges of global collaboration and the functionalities of technology that can support them in overcoming these challenges in 2016 and 2017.

The study conducted with students of the GS is the workshop asking students to identify the challenges of global collaboration and the functionalities of technology that can support them in overcoming these challenges in 2016 and 2017. The surveys and number of students involved in the surveys over the years are summarised in

Table 2-1: Preliminary investigations and number of students involved

Project and year (in order of	**Number of students involved**	**Number of students involved in each study (% rep.)**
GDP 2015	34	6 respondents for all 6 teams (representing all students) for the survey on technology use.
GS 2016	27	26 Workshop (96%).
GDP 2016	45	34 Survey on attitudes (75%); 34 Survey on technology use (75%); 26 Workshop (57%).
GDP 2017	25	18 Survey on technology use (72%); 18 Workshop (72%).
GS 2017	30	28 Workshop (93%).
GDP 2018	32	25 Survey on technology use (78%).

Most studies involved the majority of students involved in the projects, however as the workshops were offered as a voluntary attendance outside of class time, and accounting for students who missed the class time for any reason, there were some situations where all students could not be involved in the research.

In conducting this research, there was a notable change in the motivation of the research in understanding the Global Design context. The motivation of this study was prompted by an observation of students use of SNS to conduct distributed CSCD projects. During the investigation in identifying the technologies used by students as part of the GDP, there is a natural change in the technologies students chose to use towards novel technologies with similar functionalities to SNS, but that cannot be categorised. These technologies were messengers and team management platforms, along with the regular videoconference and cloud storage as identified by Mamo et al. (2015).

The scope of the preliminary investigation widened to all technologies which can be used for CSCD and not focusing on a particular category. This change is implemented in the questions asked in Chapter 2.2.2 and 2.2.3, where technologies that aid ‘social’ tasks (emphasis on *social* related to SNS) are replaced with questions asking about ‘personal communication’ and ‘Project communication’. This supports a broader project-orientated investigation into the technologies that support CSCD design activities. If this change was not made in the 2017 questionnaire, the true nature of technology that can be used in CSCD project work would not be captured. The Preliminary investigation led to this realisation.

2.1 Attitudes towards the use of social network sites in the Global Design Project

In 2016, students were accustomed to the use of social network sites to facilitate their design activities and collaborative practices. Hurn (2012) investigated the use of web 2.0 technology, particularly blogs and social network sites, in product design higher education. Of interest is that over 70% of students in his survey reported using social software for discussing project work. Considering the popularity of these websites for academic work, this presents the question; ‘are students being supported appropriately in their use of social network sites?’

Sheriff (2012) reported on the use of web 2.0 applications by academic staff in an engineering department. It was established through a survey that the majority of academic staff do not use social networking platforms and do not believe that they require training on social networking. Sheriff also reported that approximately 65% of students use social network platforms socially and do not believe they require training to assist them in using it within an academic setting.

Reflecting on these surveys of students within an engineering and design context, a questionnaire was developed to understand the attitudes of students of the GDP. 34

students, all University of Strathclyde students involved in the GDP 2016, responded to the questionnaire. Students were enrolled in the final year of a Masters' or Bachelors' degree.

In addition to the survey of students, five academic staff were asked to complete a questionnaire on their ability to teach students the best practices in SNS use for engineering design projects. Staff are involved in the teaching of lectures, supervision of students and coordination of the class at different institutions.

Students who responded to the questionnaire were asked to provide demographic information of age and educational background. Students were aged between 21 and 32, with the mean age being 24. This age group are those born between 1984 and 1995 and are colloquially known as millennials. These students are those who have high digital device ownership, high internet use, high participation in online activities, high use of online social networking and are often multitasking in their technology use (Johri et al. 2014). Students had educational backgrounds in, product design engineering, product design innovation, global innovation management, mechanical engineering and electrical engineering.

The questionnaire was distributed to students of the GDP online using a URL link. After the regular lecture time, students were encouraged to visit the link and answer the questions. The questionnaire was distributed in week three of the eleven weeks of the GDP as the questions did not intend to learn about the student's experiences of the class but intended to learn about their opinions on the use of SNS. Individual responses to the questionnaire are available at: doi.org/10.15129/03df66c3-6fe7-49b1-96fd-c1edac371bb6.

Three questions were created to investigate students' attitudes towards the use of SNS, the teaching of SNS within the GDP and the use of SNS in future careers. One question was asked of staff of the class to investigate if they feel prepared to teach students the best practices in SNS. These questions created were:

- Students
    - Do teaching staff have the appropriate attitude towards the use of social network sites to support your project work?
    - Are teaching staff capable of teaching you best practice in the use of social network sites?
    - Do you expect to be able to use social network sites as a communication tool in your future career?
- Staff
    - Do you believe you have the knowledge to teach students best practices in the use of social network sites to conduct their project work?

The response to the first question, “Do teaching staff have the appropriate attitude towards the use of SNS to support your project work?” revealed that 70% of students believed that staff endorse the use of this novel technology within an educational environment, as illustrated in Figure 2-1, Students were encouraged to explore the benefits of many communication methods, including SNS, and this may suggest why they felt supported. This is in consideration that no special provisions within the GDP class were made to support or indicate support by the staff of the use of SNS.

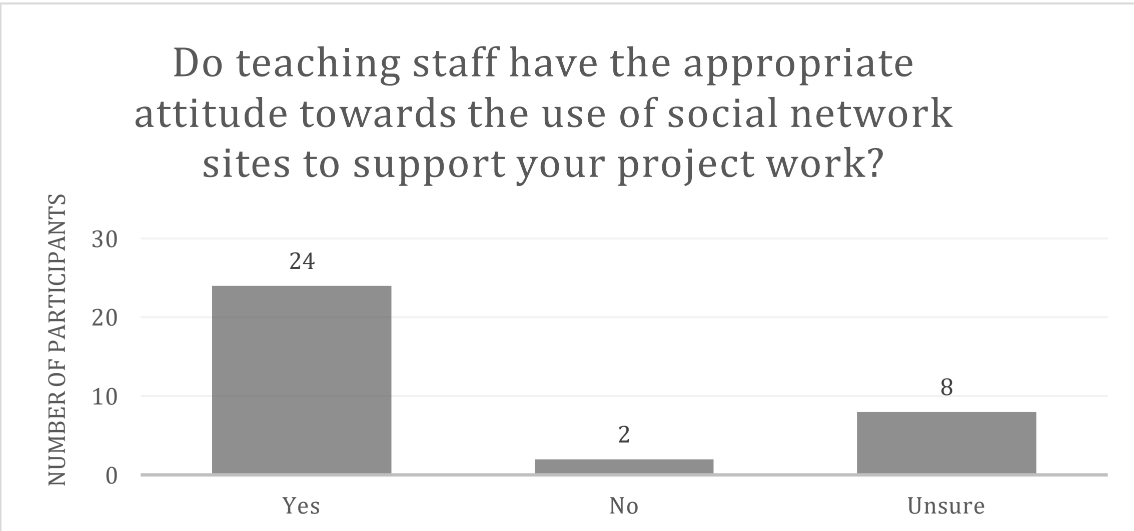

Figure 2-1: Students opinions on staff attitude towards SNS (Brisco et al. 2017)

The results of the first question were very encouraging in terms of the use of the technology within the GDP. However, the second question, “Are teaching staff capable of teaching you best practice in the use of social network sites?” revealed that the opinions of the GDP students were mixed. Figure 2-2 illustrates that only 34% of students believed staff were capable of teaching them best practices in social network site use compared to 33% who thought the staff could not teach them best practices, and 33% were unsure.

This outcome highlights those students were unsure if their education on novel technologies could be taught by the staff involved despite their extensive experience with global design over the years, e.g., the DIDET project (Wodehouse et al., 2008) and the EGPR project (Vidovics et al., 2016). Staff involved in the GDP have years of experience in computer-mediated communication and distributed collaborative design techniques, however, they may not have specific experience of using SNS. Knowledge of best practices or requirements to support design projects could be formalised and communicated to students by these experts in a more generalised way. These observations supported the decision to use relevant knowledge from relevant sources to develop the technology evaluation and selection method.

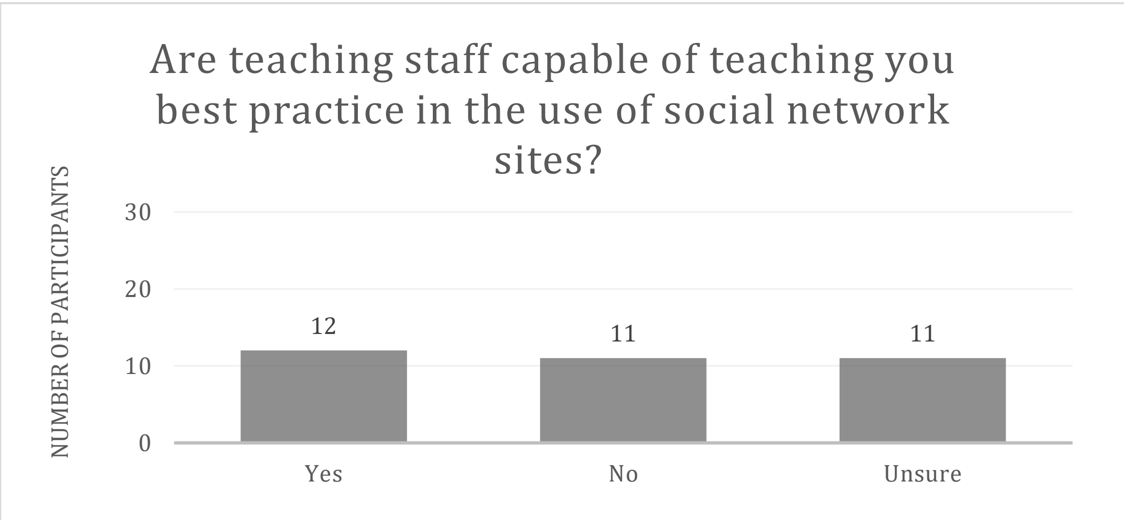

Figure 2-2: Students opinion on teaching best practice using SNS (Brisco et al. 2017)

To complete the investigation into students' opinions, students were asked, "Do you expect to be able to use social network sites as a communication tool in your future career?" This question was important as an assessment of how prominent students believe social network site technologies were within their educational environment and if they believed there were benefits to the technology that an employer may utilise in the future.

The results were overwhelmingly positive for this, as illustrated in Figure 2-3, with 80% of students believing that SNS would be used as a communication tool in the future. Students may have limited industrial experience and can only reflect on their own experiences of technology. However, SNS offer a convenience to communicate that other technologies did not, as well as integrating with daily personal and professional life in a way other technologies have not.

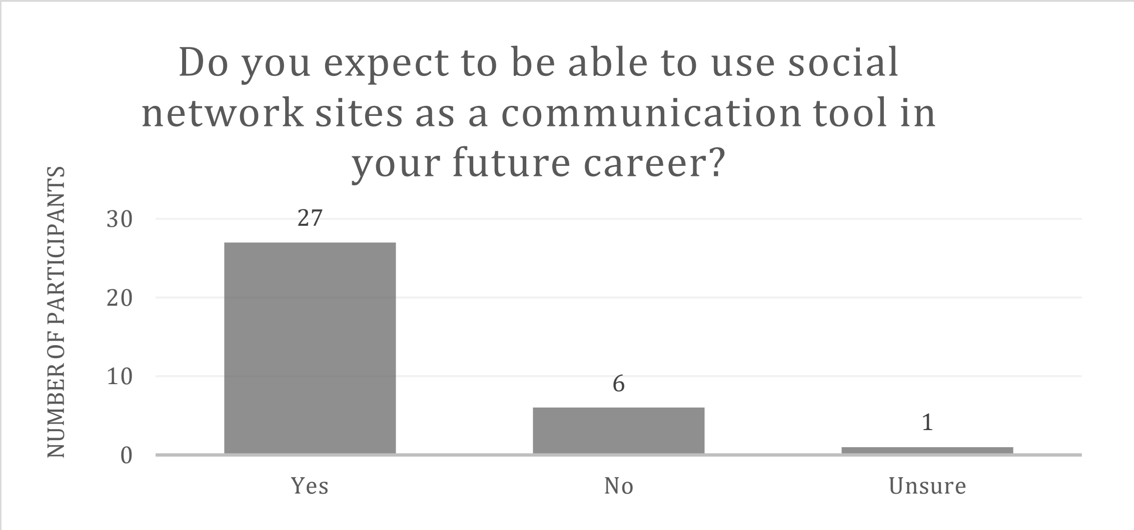

Figure 2-3: Expectation of student to use SNS in future careers (Brisco et al. 2017)

To understand how confident staff involved with the GDP class were on their abilities to teach of the use of SNS to support project work, the following question was used: “Do you believe you have the knowledge to teach students best practices in the use of social network sites to conduct their project work?” This question mirrors that which was posed to students, and students were mixed in their response.

Figure 2-4 illustrates that 40% of staff were unsure if they had the ability to teach best practice, whilst 60% stated that they did not. This indicated that best practices for these technologies are not known, at least within the global design context, and that better educational experiences should be investigated. Specific written guidance on the use of particular SNS could quickly become outdated with the speed that technology changes. However, the requirements of CSCD have been documented in the literature, as is explored in Chapter 4 & 5.

In addition, it may be assumed that if there was a need for a method of technology evaluation and selection, there may also be a need to ensure that students were educated on the implementation of this method and could utilise it to support the selection of the most appropriate technology to support their project work. If staff were unable to teach on best practices in the use of novel technologies such as SNS, then a class module or evaluation method could be developed to teach students how best to conduct their collaborative project work supported by technology. If the requirements of CSCD are formalised, then a method of technology evaluation and selection would be possible considering the changes in technology over time.

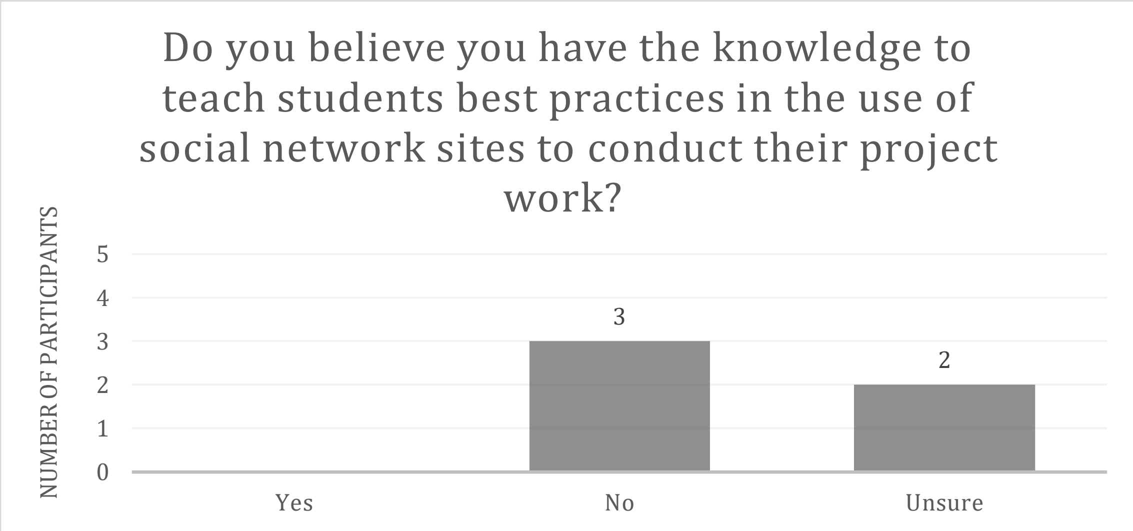

Figure 2-4: Staff opinion on teaching best practice when using SNS (Brisco et al. 2017)

The results of the survey indicated that students of the GDP using novel technologies such as SNS, felt supported in their use of these technologies. They were unsure if staff would teach them best practices and felt they would be using SNS in future careers. Staff did not believe they could teach best practices on the use of these novel technologies. From observations of the types of technologies used, there was a motivation to establish which technologies were selected to support their GDP's. Once established there can be an investigation into the characteristics of these technologies to better understand why students choose to use them and why they are suitable for use in the GDP.

2.2 Identifying technologies that support CSCD in the GDPs

As discussed within Chapter 1.3, the students of the GDP use technology to facilitate collaboration between team members located in different universities around the world. The GDP presented an opportunity to survey the students as they engaged in the normal activities of their project work as opposed to creating investigations where technology use could be artificial.

To identify the technologies used to support students CSCD, surveys were conducted during the GDP class at the University of Strathclyde in the 2015, 2016, 2017 and 2018 academic sessions. The class facilitated learning about, and experience of, a distributed product design project with team members from around the world. Teams were encouraged to explore and use any supporting technology they deemed appropriate to facilitate the collaboration of team members.

Observations and remarks were made during the 2019 academic session to introduce Microsoft teams as a collaborative technology; however, no formal survey investigation took place.

The questionnaire was distributed to students of the GDP classes over these academic sessions that asked them “which technologies do you personally use?” and “which technologies did you use as part of the GDP?”. Both personal use of technology and use as part of the GDP were asked to identify if there were similarities in the technology used e.g., selection of technology for GDP related to the popularity of the technologies personally.

The questionnaire was distributed online using the Strathclyde Qualtrics software. A text box was provided to collect responses. Respondents to the questionnaire were asked to agree that their data would be used within the research project and to provide an email address if they wished to be contacted about the results of the survey. Demographic information was collected from each respondent including team number, age and educational background.

The wording used within the questions evolved as the scope and purpose of the research became more refined, however, the results that emerged are comparable as a snapshot of the technologies that the students used each year. The specific questions are included below for each year academic session.

2.2.1 Global Design Project 2015

Data was collected from the six teams who took part in the GDP 2015 to determine which technologies were most popular with students to conduct their CSCD teamwork.

A questionnaire was distributed on week seven (midway through the projects) to ensure that students had enough time to experience the projects and their communication methods. The questionnaire asked the following two questions:

- Q1. Which technologies did you use regularly before joining the GDP for personal communication?
- Q2. Which technologies are you using to facilitate your GDP?

The focus at this time was to understand the technologies for team communication, however, key technologies such as project management and cloud storage were not recorded in response to these questions.

These questions were chosen to capture the technologies that the students were aware of in their personal lives and determine if there was a link between those used for personal communication and project communication. Through observations, the researcher expected that these technologies would be similar, if not the same, due to their popularity. From speaking with students after the results of the survey, popularity or pervasiveness in students' personal lives appeared to be a deciding factor when choosing technologies for the GDP.

The questionnaire was created using the online software Qualtrics, and responses were stored on the Strathclyde servers. Each team was asked to complete the survey as a group during class time.

The results are illustrated in Figure 2-5. These demonstrate that team members were using technologies for personal communication such as Facebook (all six teams), Snapchat (all six teams), Instagram (five teams), WhatsApp (five teams), Skype (three teams), Kik (two teams), and a small number of other technologies such as Twitter, Viber and YikYak (one team).

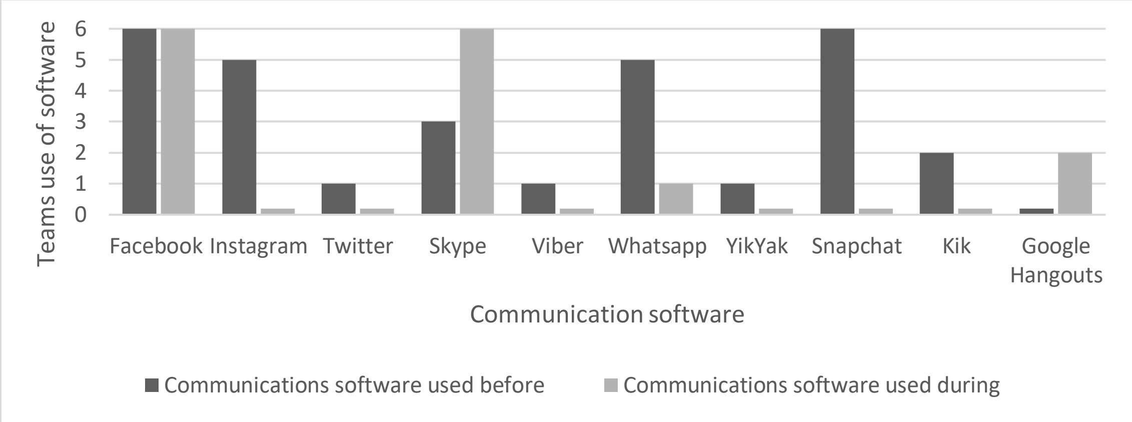

Figure 2-5: Students use of communication technology before and during the GDP 2015 (Brisco et al. 2016)

During the GDP, team members use Facebook (all six teams), Skype (five teams), Google hangouts (two teams), and WhatsApp (one team). From the results, it can be determined that a smaller number of technologies were used during the projects than students used in their personal life (nine versus four), indicating that there was some decision made by students on which technologies would be best to use. This is further discussed in Chapter 2.2.6.

2.2.2 Global Design Project 2016

In the 2016 academic session, the results of the technology use were recorded by individual team members rather than by the team as a whole for a higher fidelity of technologies reported for personal use. 34 students took part in the survey which was all students involved in the GDP 2016 at the University of Strathclyde. Students were asked to list technologies they use for social communication, planning social events, and discussing coursework/project work as part of the GDP.

The questionnaire was created using Qualtrics with text boxes to collect responses. The questions asked were:

- Q1. Which technologies do you use for social communication?
- Q2. Which technologies do you use for planning social events?
- Q3. Which technologies do you use for discussing coursework/project work as part of the GDP?

Two social aspects were chosen to investigate if there was a difference in the use of the technologies for communication and for a social task such as planning a social event outside of the GDP. The technology used for social communication is analogous with the type of functionality required for teambuilding and project communication in an educational environment. This question aimed to determine if there were similarities between communication technologies used for social and GDP. Technology used for planning social events is analogous to coordination and management tasks in an educational environment. This question aimed to determine if there were similarities between task-based technologies for social and GDP.

The results of the questions are illustrated in Figure 2-6. In total, seven SNS were identified. For social communication, Facebook was the most popular technology (32 of 34 respondents), followed by Instagram (17 respondents), WhatsApp (18 respondents), Snapchat (13 respondents), Twitter (four respondents) and Slack (one respondent). To plan social events, Facebook was once again the most popular technology (31 respondents), followed by WhatsApp (15), Snapchat (two respondents) and Slack and Instagram reported by only one respondent.

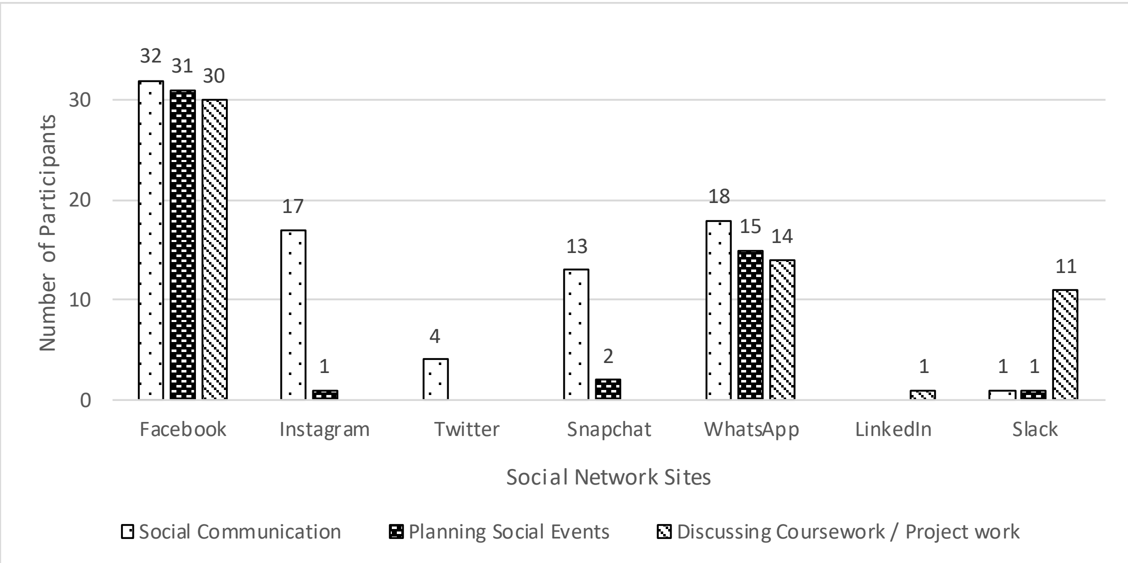

Figure 2-6: Comparison between the use of social network sites for personal communication, for the social task of planning an event and the academic task of discussing coursework/project work by students (Brisco et al. 2017).

Within the 2016 academic session, a smaller number of technologies were reported as being used to facilitate CSCD project work in comparison to 2015. Facebook was once again the most popular (30 respondents), followed by WhatsApp (14 respondents) and Slack (11 respondents). The results, once again, demonstrated that students chose to use a smaller number and types of technologies than they use personally, suggesting that they selected technologies to use for the projects based upon their experiences of the technologies, in turn indicating some evaluation and selection of technologies informally. This is further discussed in Chapter 2.2.6.

2.2.3 Global Design Project 2017

During the 2017 academic session, all students of the GDP at the University of Strathclyde, 18 students, responded to a questionnaire asking which technologies they used for personal communication and project communications during the GDP. The questionnaire was sent to individuals of the GDP on week 7 (midway point for the projects). Students were asked the following questions:

Q1. Which technologies do you use for personal communication?

Q2. Which technologies do you use for project communication as part of the GDP?

Participants were provided with a textbox to respond to the questions and asked to list all communication technologies they used.

The questions were adapted due to a change in the focus of the research. Whilst the motivation of the investigation began with a focus on the use of SNS in the GDP, the motivation soon grew to determine which technologies are best used for CSCD. As the answer may not be SNS or other social media, the scope of the identification of technology was increased.

Students were encouraged to respond with all technologies and not specifically focus on SNS, as it was believed that there had been some technologies utilised that were not collected by previous surveys. Team management technologies and instant messengers did not technically meet the specification of a social network site, and technology functionality was changing to make these differences more distinct. This also led to a change in the motivation of the research away from the use of SNS that support project work in general, and towards the use of novel technologies to support CSCD. The questionnaire was created using Qualtrics.

The results of the questions are displayed in Figure 2-7. A total of 15 technologies were identified. 14 were identified for use in student's personal communication, including Facebook (16 respondents out of 18), which was the most popular technology at the time, Instagram (five respondents), WhatsApp (five respondents), Skype (two respondents), Facebook Messenger (two respondents), Email (two respondents) and Twitter (two respondents), and a large number of technologies only popular with one respondent being; Trello, Google Docs, LinkedIn, Google+, Discord, iMessage and Line.

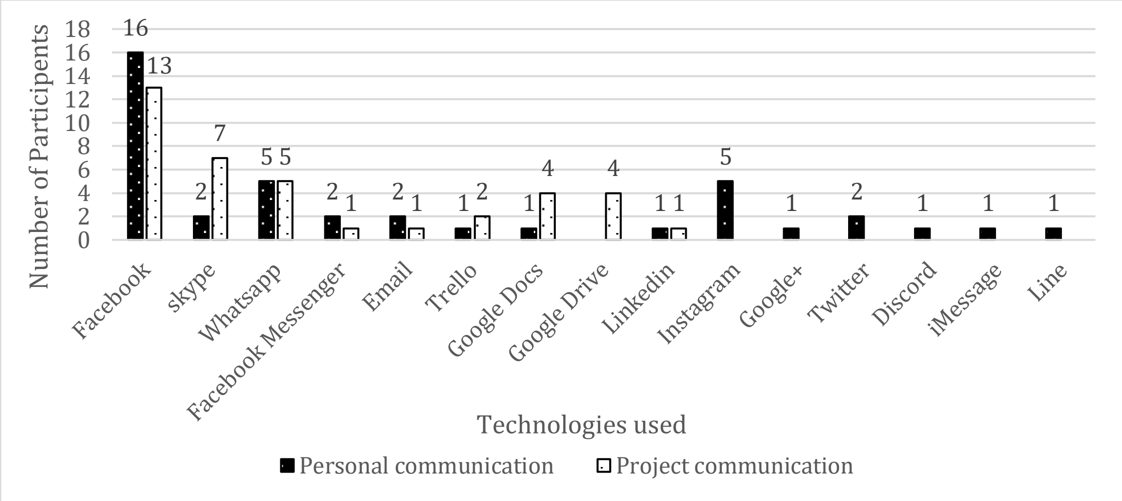

Figure 2-7: Comparison between the use of technologies by students for personal communication and project communications in GDP 2017

Nine technologies were reported as being used during the GDPs by respondents. Facebook was again the most popular technology used for project communication in the GDP (13 respondents) followed by Skype (seven respondents), WhatsApp (five respondents), Google Docs and Google Drive (four respondents each), Trello (two respondents) and one respondent each for Facebook Messenger, Email and LinkedIn.

Once again, respondents reported more technologies used for personal communication than project communication. Facebook messenger was first reported separate from Facebook this year due to the separation of the platform and the messenger in separate apps on mobile devices. Google Drive was a technology reported as used by project communication but not personal communication. Skype and Google docs were more popular for project communication than personal communication, indicating that their purpose was better suited for project work than personal communication. These aspects are further discussed in Chapter 2.2.6.

2.2.4 Global Design Project 2018

In the 2018 academic session, 25 students took part and responded to a questionnaire asking which technologies they used in general, and which were used as part of the GDP.

Again, the question was slightly changed, asking for any technologies students used in their “personal life” and technologies used “as part of the GDP” and not specifically technologies used for communications. These questions were:

Q1. Which technologies do you use for personally?

Q2. Which technologies do you use for the GDP?

In addition, students were encouraged to report all technologies individually that may be packaged together, e.g., Facebook and Facebook messenger (rather than just Facebook) or Google Docs, Google Drive, Google Forms (rather than just Google) and others. IT was decided to encourage students to list all technologies as it was noticed some technologies were missing from previous surveys which were popular or pertinent to CSCD in particular the cloud storage technologies used by students.

Participants were asked to list all technologies they used and provided a text box to answer each question. The results are illustrated in Figure 2-8.

21 technologies were reported in total, with 15 used personally and 14 used for the GDP. Students were encouraged to explore new technologies that may support the GDP. Those identified by students include AR viewers for viewing CSD in real life, Wonderlist for creating shared task lists, and Mindmup for discussing and planning the design process as a team. Many google products were popular for teamwork but were not used personally by the students outside of the projects.

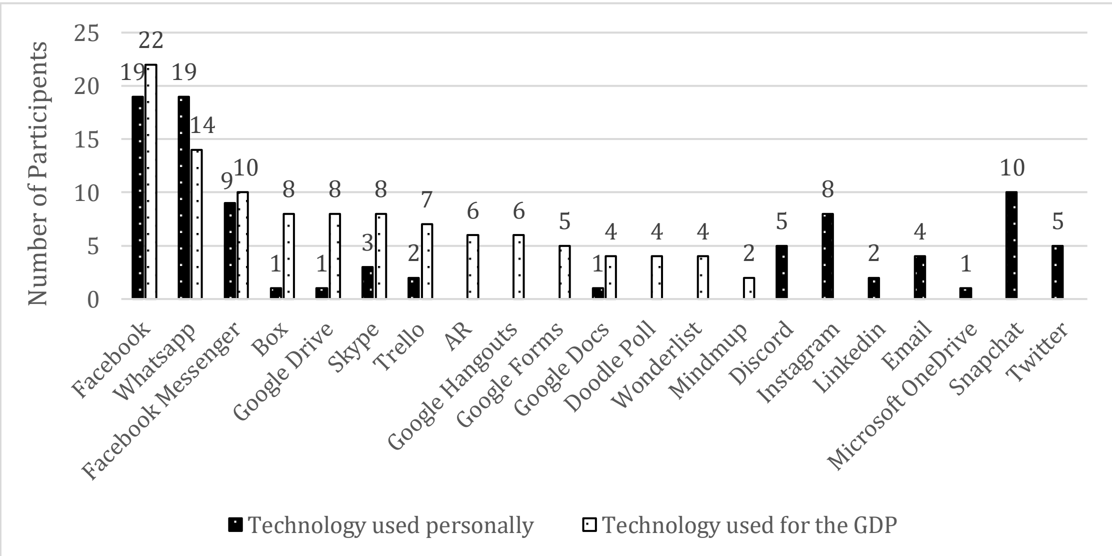

Figure 2-8: Comparison between the use of technologies by students for personal communication and academic communications in GDP 2018

In the 2018 survey, Facebook had a higher use in 2018 for the projects (88%) than was reported for personal use (76%). This was the first session that Facebook had a higher reported use within the projects than personally by students, highlighting the suitability of Facebook for the GDP and engineering communication in general.

WhatsApp appeared to return to the level of usage within the projects in 2016 (56%), indicating that the lack of use with participants in 2017 was not a trend for a decline, but a temporary deviation by students that year. However, other messengers continued to increase in usage, such as Facebook Messenger, which was understood as a separate tool to Facebook by this year, personal use was reported by 36% of participants and 40% during the GDP. Once again, students used messengers for quick synchronous communication, and Facebook and other project management platforms (such as Trello) used for asynchronous communication and coordination.

In 2018 a more extensive range of cloud storage platforms was reported. Box, Google Drive and Microsoft OneDrive were reported by 4% of respondents for personal use, but Box (32%) and Google drive (32%) was reported for use within the projects. It may be expected that the use of cloud storage would be used by all participants as it was one of the essential tools identified by Mamo et al. (2015), However, technologies such as Facebook, Google docs, Google Hangouts and Skype offer the ability to save and send files that also means they can be stored. Many students chose to store the documents on a social network site platform or another sharing platform rather than a cloud storage platform. This can cause problems for version control as alternative platforms do not have high integration of storage protocols.

Once again, Facebook (88%) was used by some teams during the projects for video conference meetings along with Skype (32%) and Google Hangouts (24%). Discord is a more recently launched video/audio conference technology commonly used by gamers that some reflected could have offered better video quality and may be used by students in future versions of the class. Facebook Messenger and WhatsApp also offer video conference functionality. These technologies are competing with the same functionality, presenting problems for clarity of communication and identifying the best solutions. No teams identified enterprise-level solutions such as Skype for business, GoToMeeting or BlueJeans.

AR technologies were identified by students in the survey (24%) in 2018 to display CAD models in real-life environments and offering a visualisation of the scale of the models in real life. This year was not the first use of these technologies by students in the class. This signifies that these types of technologies are becoming more recognisable and relevant to facilitate the projects. Additionally, Wonderlist was used by 16% of students, which has similar functionality to Trello.

2.2.5 Global Design Project 2019

No survey was taken in 2019 as the GDP took place after the development of the evaluation and selection tool presented in Chapter 6. Due to the development of the evaluation and selection tool, a switch in the focus of the research took place towards the solution. Research in the GDP 2019 was utilised for other purposes of evaluation and the development of an online CSCD course, as discussed in Chapter 8. However, during this session, there were some observations of the author relevant to the discussion on trends across the years.

In 2019, students chose to use Microsoft Teams to facilitate project management. Teams has become a popular technology as a result of the COVID-19 virus and stay and work from home orders around the world. The technology in 2019 offered a messenger style text chat as the main interface, video conferencing, document sharing, polling and voting, notifications and tagging. Modules can be added to extend the functionality of teams with partners or simply using URL links. Teams enables many of the required functionalities usually supported by a social network site, cloud storage and video conferencing. Microsoft Teams could become an all-in-one platform to support team communication.

In 2019 there was a noticeable reduction in Facebook's use in favour of simpler messenger platforms such as WhatsApp and Facebook Messenger. It seems this was encouraged through declining popularity in the use of Facebook for both personal and social communication.

2.2.6 Discussion on the use of technologies that support CSCD in the GDP

In this section, the results of the surveys of the GDP 2015-2018 academic sessions are discussed, reflecting on the technologies that students chose to use and the general implications for GDP. To support the understanding of the results of the survey, informal interviews were performed with all students of the GDP across all sessions. The mixed-methods approach supported a more complete understanding of the results in the context of the GDP.

Interviews took place informally, on a weekly basis during the GDP during dedicated class and project work time. These interviews enabled the researcher to understand the technologies, their functionalities, and the extent to which they supported the design process. Formal or structured interviews were not conducted as the surveys acted as a structured data collection that could be discussed with student teams and individuals to get collect more information.

The types of questions asked at the informal interviews included asking of any issues that have occurred as a result of collaboration with other team members (human to human issues) or as a result of technology use (human to computer issues). The outcomes of the interviews with students are recorded in Appendix 11, discussed in Chapter 6.

The key themes that emerged in exploring the data were Facebook's popularity as a social network site, specific issues with the usability of particular technologies based on global issues, and the emergence of novel technologies for CSCD teams identified in the final two years of study.

There were several changes in technology use between each year of the GDP's as recorded in the survey response. These will be discussed as follows.

Students reported personal use of Facebook less in more recent years but identified Facebook as a suitable tool for project work through the experience of using it in previous projects. Facebook was reported for personal/social use in 2016 by 94% of students, in 2017 by 88% of students, and in 2018 by 76% of students. In 2018, and reflecting on the drop in popularity of Facebook, 89% of student chose to use Facebook for the GDP. This indicates that although Facebook is in declining popularity for personal use, students found it suitable for project work as a part of the GDP.

Teams explained during interviews that Facebook offered a "shared and secure group space" with text, image, video and document sharing. Users stated that they engaged with syndication and social tagging functionality to increase awareness and alert other team members of work. Facebook was described as offering both synchronous and asynchronous communication at the same time, allowing students to engage whenever and wherever they could. In many ways, Facebook appeared to be a functionality filled solution to global collaboration.

In the GDP 2015, it was identified that two video conference apps were used: Skype, and Google Hangouts. Two teams reported using both technologies and it was unclear why they required both, and why they switched technologies. During the interviews, the students revealed that they experienced bandwidth issues with globally distributed team members using Skype, however, Google Hangouts did not have the same issues. The team switched midway through the GDP to Google Hangouts.

Across all academic sessions, the number of technologies used personally was much higher than those used within the projects (Table 2-2). In 2015 this was nine technologies used before the projects and four used during the GDP, in 2016 six were used for social communication versus four for project work, in 2017 14 were used for personal communication and nine for project communication during the GDP, and in 2018 15 technologies were used personally by respondents and 14 were used during the projects.

One trend in this overview data is the increase in the number of technologies reported. This could be due to encouragement to explore novel technologies to support CSCD or could be the way in which the questions were asked over the years, moving from a focus on SNS to any and all CSCD technologies.

Table 2-2: Number of technologies used in each year of the GDP

Year	**Personal**	**GDP**
2015	9	4
2016	6	4
2017	14	9
2018	15	14

From 2016 onwards, students identified Slack in the response to the surveys as a team management and communication tool used for their GDP. Also, from 2017, Trello, an online project management software allowing teams to track the completion of tasks was identified in the response to the survey as used during the GDP. This project management category of technology was novel for the GDP students and appeared to be replacing the use for Facebook that was becoming less popular with the students in their personal lives.

Reflecting on the research reported by Mamo et al. (2015), there was no identified need for a project management software, yet Facebook was suggested used in each stage of the design process as suggested by Mamo. Facebook offered many of the functionalities required to communicate with and manage a team, but it was not explicitly designed for this purpose. With the dropping popularity of Facebook, students may be looking for alternatives in technologies used for project management.

As Facebook became less popular for personal communication with students, as identified in the survey, messengers such as Facebook Messenger and WhatsApp became more popular. WhatsApp was used by students in 2018 to the same extent as Facebook for personal communication. This did not indicate a switch in popularity from SNS to messengers but did indicate increased usage.

In the 2019 academic session, it was remarked that Microsoft Teams was identified and used by students of the GDP. This is anecdotal due to the lack of a survey in 2019 but highlights a reflection on the nature of the research that the technology landscape is ever-changing. In teaching the GDP as identified in Chapter 2.1, students and staff were unsure of the abilities of staff to teach best practices in the use of novel technologies such as SNS. The technology changes identified in this chapter indicate that new technologies and a technology evaluation and selection method would have to be agile to include new technologies and determine their suitability for CSCD.

Technologies have been identified across the years of the GDP, used to support a broad range of project-orientated activity. The technologies and their use within the GDP are summarised in Table 2-3. The technologies reported across two years, or more are used for communication, video conference, cloud storage and project management. Novel technologies tend to be used within a single year, which supports the need for the tool to be agile for new technologies.

A technologies suitability for CSCD is not confirmed by its existence. In order for any given technology to be considered appropriate for supporting CSCD, there is a need to demonstrate that it satisfies requirements associated with supporting collaboration. Once these collaboration requirements have been defined, it would subsequently be possible to compare two technologies to identify which is more appropriate for CSCD. A technology evaluation and selection method should feature this ability.

Table 2-3: Technologies used in the GDP from 2015-2018 sorted by the number of years reported.

Technology	**Number of years**
Facebook	4
WhatsApp	4
Skype	3
Facebook Messenger	2
Google Docs	2
Google Drive	2
Google Hangouts	2
LinkedIn	2
Trello	2
AR	1
Box	1
Doodle Poll	1
Email	1
Google Forms	1
Mindmup	1
Slack	1
Wonderlist	1

By establishing the technologies that have been used to support project activity within the GDP, it was still unclear how technologies could satisfy the requirements of CSCD. Knowledge of technologies themselves did not offer a comparison with requirements directly. However, knowledge of functionalities of technologies are comparable with both the technologies and the requirements. An investigation was conducted to determine the functionalities of technologies that could support CSCD activities.

2.3 Functionalities of technologies that support CSCD in the GDP and GS

The earlier investigations revealed the attitudes of GDP students towards SNS (Chapter 2.1) and the technologies they chose to use as a part of the GDP projects over the years (Chapter 2.2). However, the way in which these technologies supported student projects was still unknown. Some of this information was collected as a part of the informal interviews in Chapter 2.2 and is detailed further in Chapter 6, recorded in class diaries. To understand in-depth, a focused investigation was conceived.

A workshop was developed to investigate which functionalities of technologies were used to support CSCD for the GDPs. The workshop was conducted with students from two different global design modules: the GDP, and the Global Studio class at Loughborough University Design School (described in Chapter 1.3), to gather responses from a broader set of students.

Four physical workshops were held over a two-year period with students experienced in global design. The workshops introduce the complexities of distributed design before asking students to critically analyse their practices and create ways to overcome the challenges of distributed design. All workshops included an introduction to the field of distributed design to ensure all participants have a shared understanding of what is CSCD? And collaboration in general.

Workshop one took place at Loughborough University design school with 26 students of The Global Studio 2016. Workshop two took place at Strathclyde University with 26 students of The Global Design Project 2016. Workshop three took place with 18 students of The Global Design Project 2017. And workshop four took place with 28 students of The Global Studio 2017. 98 students were involved in the workshops over the years.

Teams of students were formed of between four and six participants. Students were invited to form their own teams. Teams were supplied with paper, marker pens, and post-it notes to complete the workshop activities. Teams could display the knowledge in whichever way they felt was most appropriate, e.g., lists, mind maps, post-it-note ideation. Individual outcomes of the workshops are collated for download at: doi.org/10.15129/9647d268-c35a-4c6e-a325-caabbf64c42e.

Students were asked two questions:

Q1. What are the challenges of supporting collaboration during the design process?

Q2. Which functionality of collaborative design technologies can be used to overcome these challenges?

These questions were created to encourage discussion between team members on CSCD challenges and solutions to these challenges, in particular computer-supported solutions.

Students had 15 minutes to discuss each question and record the results of their discussion. The slides used to coordinate the session is included as Appendix 2.

2.3.1 Identification of the technology functionalities

The following section details the outcomes of the workshops. In total, 20 challenges were identified, and ten functionalities of technology were identified across all workshops. Some functionalities could address several challenges, and some challenges were addressed by multiple functionalities. The outcomes of the workshops are synthesised in Table 2-4.

Messaging addressed five collaboration challenges of; for rapid communication, to encourage all team members to contribute, knowing if a message has been read, for documentation of the process and for quick clarification. Where research in the literature may refer to a challenge of communication, the students refer to these challenges as rapid communication or quick clarification which are more descriptive to the actual problems faced in real-world projects.

Voting was a functionality that could overcome the challenge of decision making. Video conference was identified to overcome the challenges of building trust, breaking the ice and face-to-face meetings. Profiles were identified to overcome the challenges of knowing about the personality, skills and interests of team members and building trust. Networking was identified for engaging with known and unknown resources i.e., the resources that could help support the students and how they might learn of these resources.

Collaborative document editing was a functionality identified for overcoming the challenge of distributed power between team members to make decisions, for real-time synchronous updates and for project management. Electronic whiteboards were identified for collaborative drawing and brainstorming. Shared calendar was used for scheduling meeting and time for specific work. Cloud storage was identified to provide access to shared documents by all team members and to enable reflection on previous work. And finally, Task lists was a functionality to overcome the challenge of awareness of work and scheduling meetings and work time.

Scheduling and building trust are challenges supported by two functionalities. In support of the challenge of scheduling both task list and shared calendar can be employed. And to support building trust, video conference and profiles can be employed.

Table 2-4: Functionalities identified in the workshops to overcomes challenges of collaboration; adapted from (Brisco et al. 2019)

Functionalities	Collaboration challenges in GDP/GS
Messaging	Rapid communication
	Encourage all team members to contribute
	Knowing if a message has been read
	Documentation of the process
	Quick clarification
Voting	Decision making
Video conferencing	Build trust
	Breaking the ice
	Face-to-face meetings
Profiles	Knowledge of personality, skills and interests
	Build trust
Networking	Known and unknown resources
Collaborative document editing	Everyone has the power
	Delivering real-time synchronous updates
	Project management
Electronic whiteboards	Collaborative drawing
	Brainstorming
Shared calendar	Scheduling
Cloud storage	Access to documents by all
	Reflection on previous work
Task lists	Awareness of work
	Scheduling

The functionalities identified in the investigation are defined as follows:

- **Messaging** is a functionality offered by many technologies such as instant messengers, SNS and email. Messaging can be asynchronous when required to enable rapid communication and clarify information, or asynchronous when required to document a design process. Messaging can offer the ability to know if a message has been read, which was identified to improve social understanding between team members and alleviate tension. Also, messaging was identified as a method for encouraging all team members to contribute when a communication breakdown occurs, such as when team members do not feel confident to contribute face-to-face.
- **Voting** is a functionality offered in several forms but commonly as a multiple-choice question. This functionality was identified to democratically make decisions when a binary (yes/no) answer is required where all with a vote have an equal impact.
- **Video conferencing** can offer teams the ability to have a face-to-face conversation in a distributed environment. Video conferencing can come in a range of forms, from a professional setup room to a consumer mobile phone app. Having face-to-face time was identified as offering the ability for teams to 'break the ice' if they have not had the opportunity in a collocated setting, and this can assist in building trust amongst team members. Teams can share documents and screens to enable all to see shared documents or communicate ideas.
- **Profiles** are a functionality commonly associated with SNS. Profiles enable team members to share information about themselves and give an overview of their personalities. Greater social communication was recognised as a way of building trust amongst team members.
- **Networking** was identified as a method for designers and the design team to expand their capabilities by expanding their resources. This can be associated with social networking or through email gatekeepers who offer a connection to a required resource.
- **Collaborative document editing** allows teams to work on documents simultaneously, enabling all to have the opportunity to contribute. This functionality ensures that documents are up to date in real-time, and there are no difficulties with outdated versions of documents. Shared documents were

recognised as enabling project management techniques to be implemented by sharing management documents such as Gantt charts and planning documents such as resource planners.

- **Electronic whiteboards** can be utilised in design teams to share drawings live across multiple locations. This functionality was identified as enabling collaborative drawings where sketches can be edited and updated by multiple team members and can be used for ideation tasks such as brainstorming.
- **Shared calendars** are available on several platforms. It was acknowledged that team members could utilise this functionality to share their calendar and compare their own with their teams to select appropriate times for meetings or ensure all are aware of upcoming deadlines.
- **Cloud storage** was recognised as a technology to enable teams to store and access files in a shared location. All team members should have access to this location whenever required. Team members can utilise the cloud storage space to reflect on previous work by searching for information previously shared or created.
- **Task lists** were identified as a function as part of a team's project management plan to ensure all team members are aware of imminent tasks and the progress of ongoing tasks. Awareness can be useful in scheduling work to be completed.

The ten functionalities identified are not specific to any individual technology and can be implemented or employed by a technology to offer a particular functionality. There can be overlaps in functionality between technologies, however when this happens the functionality can take a different form, with different outcomes e.g., text-based messenger functionality is a different experience to live synchronous video conference due to the additional presence or seeing the other person and hearing their voice, compared to reading.

Functionalities are the connection between the technologies available and the requirements of CSCD. A technology such as Skype, has video conference functionality, enabling team members to communicate face-to-face. By using skype, communication is facilitated. When comparing technologies, it would be useful to know which functionalities the alternative technologies have, understand if they have more, or less functionalities, and if these functionalities actually contribute to CSCD requirements.

It is unclear from the preliminary investigations within the GDP and GS what the requirements of CSCD are, and how the technologies available could be evaluated to determine those which should be selected. Before the development of a solution, an investigation is required to determine if a technology evaluation and selection method exists for CSCD or to establish a gap in knowledge This is determined in Chapter 4.

2.4 Research aim and objectives

The aim of this research was:

To develop a systematic automated method to allow engineering design teams to evaluate and select suitable technologies to support Computer-Supported Collaborative Design (CSCD).

The objectives of this research in order to achieve the aim are:

- To define the requirements of CSCD.
- To define the technology functionalities that satisfy the defined requirements of CSCD.
- To establish the technologies that deliver the functionalities to satisfy the defined requirements of CSCD.
- To create an evaluation approach that compares the CSCD requirements against technology functionality to identify suitable technologies for any given CSCD context.
- To create an automated and systematic population method towards the evaluation approach.
- To evaluate the evaluation approach with data from a CSCD engineering design team project within an appropriate environment.

The knowledge outcomes of this research as documented within this thesis are:

- A literature search and review to support the identification of a knowledge gap approving the aim.
- The requirements of CSCD.
- The technologies that support CSCD.
- The technology functionalities that satisfy CSCD requirements.
- The creation of the CSCD matrix as a tool to support systematic evaluation of technologies that support CSCD.
- The semantic dictionaries used to automate the population of the CSCD matrix.
- The coding of the text processing method used to automate the population of the CSCD matrix.
- The evaluation of the use of the CSCD matrix within an appropriate environment.

2.5 Research questions

To meet the aim of this research, the following research questions were formulated. The primary research question (RQ1) is answered by identifying and investigating secondary research questions (RQ1.1-RQ1.6). These are:

RQ1. Can a systematic automated method be established to support the selection of appropriate technologies for CSCD in engineering design team projects?

- RQ1.1 Which technologies are used to support CSCD? (Chapter 2 & 4)
- RQ1.2 What technology functionalities are used to support CSCD? (Chapter 2 & 4)
- RQ1.3 What are the requirements to support CSCD (Chapter 4 & 5)
- RQ1.4 What is the nature of the relationship between technologies that support CSCD, the functionalities of those technologies and the requirements of CSCD? (Chapter 6)
- RQ1.5 How can such a method be utilised dependably? (Chapter 6 & 7)
- RQ1.6 How successful can such a method be in supporting engineering design teams to identify the appropriate technologies? (Chapter 8 & 9)

In order to answer these research questions, there are some cases that need to build upon the knowledge established within earlier chapters. For example, RQ1.4, which is answered in Chapter 6 relies upon knowledge built and transferred in Chapters 2, 4 & 5.

2.6 Summary

This chapter details the results of the preliminary investigation into a change in student behaviour towards using novel technologies to facilitate CSCD project work.

A questionnaire was distributed to students of the GDP class at the University of Strathclyde in 2016, asking students and staff questions related to novel technologies, particularly SNS. The results reveal that students feel encouraged in their use of SNS and expect to be able to use the tools in future careers. Students were unsure if staff of the GDP had the right knowledge to inform their education on best practices when using SNS and staff also did not believe they were best placed to inform these practices.

Based on the opinions of the students and staff involved in the class, an investigation was conducted to learn which technologies were used by students in support of their GDP work. Over the years, the technologies used changes as availability, awareness, and trends changed. 16 technologies were identified, of which nine were used in more than one year. The identification of these technologies can support the creation of a list of technologies to characterise the types of technologies that support CSCD work.

An investigation was developed to understand the functionalities of technologies used by students during their CSCD projects. To investigate these functionalities, a workshop was developed to identifying the functionalities of technologies that support student CSCD projects. In addition to the GDP, the GS class was involved in performing these workshops with a wider range of students. Students during these workshops were able to create a list of ten functionalities that can overcome 19 challenges of CSCD.

Aims and objectives were established to formalise the motivation based upon the preliminary investigation. Research questions were established to guide the research approach development and to support the evaluation of the research.

Following the preliminary investigation, there was a need to investigate the research approach, enabling the research questions to be answered. This should be based upon a scientific and philosophical basis, as discussed in chapter 3.

3 RESEARCH APPROACH

This chapter discusses the decisions made to support the development of the knowledge contribution. The essential considerations that define the scope of the research and the approach are discussed. Research approaches are reviewed to establish the possibilities for this research, and to convey the author's knowledge on the subject. The selected approach is detailed, and the reasons for the fit with the author's worldview are explained.

In preparation for the research, the following sections will detail the considerations for the research approach selected. This type of research is exploratory: the aims and objectives evolved and emerged throughout the project. Where this has happened, a clear explanation of the change is given.

Saunders et al. (2000) suggest that the first step towards the research approach is to clarify the requirements of the research inquiry, determine the research question, aims and objectives (Chapter 2), and then transform this into a proposal through a sound philosophical understanding.

The following research approach considerations are explored: what makes a good research approach? Specifically, towards the aim of PhD candidature and the contribution to knowledge, and to evaluate the outcomes of the research, the research philosophy to ensure a sound scientific grounding. A research approach map is included that visually details the source of knowledge, the activities or knowledge transfers that occur, and the contributions to knowledge (primary and secondary).

3.1 What makes a good research approach?

Saunders et al. (2000) take a pragmatic view of what makes a good research approach. They claim the most crucial emphasis for PhD research is the requirements of an examination (such as a viva examination) if applicable. Considering this notion, the approach of this research has been characterised by the requirements of the examination. Saunders et al. (2000) continue with their assertions that there would be "no benefits to conducting research towards a PhD which is not of the calibre to achieve one" and suggests four *practical* criteria for success:

- The researcher must have the ability to conduct the research practically;
- The researcher must have the ability to conduct the research financially;
- The researcher must have access to the relevant data; and,
- The research must contribute towards the researcher's career goals.

The research approach considered to complete the research in this thesis has been considered on all four of these points. In addition, Saunders et al. (2000) suggested two criteria that are not practical in nature. These are: that the research must link with theory; and that the research must have value. These two criteria relate to the success of the examination. Within this thesis, the research will be based on theory established by the literature review and sources of knowledge, and the value of the research is evaluated based on its success within a specific task-based context.

The research was achieved within the timeframe and financial regulations as defined by the funding body EPSRC and the University. Financial contributions were utilised to attend conferences for knowledge exchange, conduct workshops, and visit other educational institutions to learn about their practices. Utilising the GDP and GS, the relevant data required to conduct the study within an educational environment was accessible.

The research was focused on the educational impact for the GDP and collaboration in design engineering as these topics are within the researcher's interest and towards the researcher's career goals. The research was linked to theory by aligning the method with the E2 design activity model with CSCD considerations (Brisco, Whitfield & Grierson 2018) and conducting a systematic literature search and literature review of peer-reviewed papers. The research value was evaluated by processing the GDP 2018 data, using student, academic and expert feedback, and the creation and evaluation of workshops and an online short course educating students of CSCD.

3.2 Research philosophy

Easterby-Smith et al. (2002) - Page 27 claimed that there are three practical outcomes from considering philosophical issues that support the research process. The first outcome: "It can help to clarify research designs", where research design refers to the planning and preparation of the overall research project. This outcome ensures the researcher is evident in their plan and the process they will follow to answer their research questions. The second outcome: "Recognition of which research designs will work and which won't", ensures the researcher has critically considered multiple options for the research and has selected the most appropriate with the knowledge they currently hold. Finally, the third outcome, "Create designs which might be outside the researchers past experience", ensures the researcher is exploring all possible research designs to select the most appropriate for the work, not for themselves or their world views.

A worldview originates from an individual's perspective. The traditional scientific world view is an objective perspective; that is, research is external to its subject. In modern philosophy of science, there has been a paradigm change from an objective world view towards a social construct world view (Easterby-Smith et al. 2002). A social construct world view does not externalise research from its subject but states that the observations of the subject are reliant to the research. The results are subject to the researcher's interpretation of the scientific observations.

Research philosophies are defined by four dimensions; these are paradigm, ontology, epistemology and methodology (Scotland 2012). To ensure a complete, robust and consistent research project, the recommendations by Easterby-Smith et al. (2002) are considered and utilised in the research approach as follows in Chapter 3.2.1 - 3.2.4. These sections represent the authors understanding of research philosophy and justify the decisions made towards the research approach, as detailed in Chapter 3.6.

3.2.1 Research paradigm

Kuhn (1970) stated that "a paradigm is an accepted model or pattern" within research philosophy and is subject to "further articulation and specification under new or more stringent conditions". A paradigm is an accepted belief system representing one world view that guides how research investigations are conducted. It is accepted but is subject to change, as the understanding about a phenomenon changes. It is unlikely that a paradigm is challenged in principle, but it is essential that it can be.

Within this research, several paradigms were explored surrounding the requirements of CSCD, the technologies that enable CSCD and the functionalities of technologies that satisfy the requirements of CSCD. Beyond these core knowledge areas, there are paradigms of engineering, design, education, teamwork and many others that impact the work. These are explored in the literature search and review (Chapter 4).

There are three purposes of a paradigm according to Kuhn (1970), these are: "1. The paradigm must be shown to be revealing about the nature of things. 2. The paradigm must offer the ability to predict and compare theory with reality. 3. The paradigm must be articulated empirically resolving ambiguity and problems".

Towards the aim of this research, there will be a focus on paradigms that reveal the nature of the development of a systematic automated method, allowing engineering design teams to evaluate and select suitable technologies for CSCD. Theories of CSCD can be compared against real-world contexts empirically. The paradigms will support the evaluation of the work for comparison with reality to be discussed in detailed nuance.

3.2.2 Ontology

Easterby-Smith et al. (2002) defined ontology as "assumptions that we make about the nature of reality". Where the paradigm is the model that characterises reality, the ontology reflects a consideration of what reality is. Easterby-Smith et al. (2002) defined four world views along the spectrum of ontology.

Traditional realism is an objective view typically associated with factual science. The world is how we see it, it is factual, and our observation of it, does not change it. For research philosophy, this means "science can only progress through observations that have a direct correspondence to the phenomena being investigated" (Easterby-Smith et al. 2002). This view reflects the belief that there must be visible evidence to know it is true, and once it is a fact, it is independent of further observation, which is a typical viewpoint of scientific investigation, such as in the study of physics.

Internal realism is the world view that: "whether or not phenomena are concrete, it is only possible to gather indirect evidence of what's going on" (Easterby-Smith et al. 2002). The implication here is that not all can be fully observed to understanding, but theories can be proposed. This viewpoint introduces problems with a traditional realism view that truths can be observed, but the act of observation will change the results of the experiment (Easterby-Smith et al. 2002). This view is known as the observer effect common to quantum mechanics.

Relativism is prevalent in modern sciences, especially the social sciences. It is the world view that each observer has their own interpretation, and each person creates their view of reality (Easterby-Smith et al. 2002). To research with a relativism world view, researchers must have a consensus, requiring multiple observations of a phenomenon and agreement in the field. Relativism can be applied in the field of design research when the nature of the research topic is novel and exploratory, such as with case study research methods.

Nominalism goes beyond relativism in that it is acceptable for multiple viewpoints of a phenomenon to exist. Facts are not concrete, and they are human constructs (Easterby-Smith et al. 2002). Knowledge can be gained from an individual's experiences and interpretation, but there is no consensus requirement. Again, this is popular within the social sciences and has enabled methods of inquiry such as grounded theory.

Realism is not an appropriate mode for the research as there is inherently an issue with observation. Some actions of team members can be observed, that is, if they decide to perform a task, i.e., draw a sketch of a concept to share it with others. However, the thought and decision making involved in the production of that sketch is not currently observable.

There were situations where interpretation of results could impact the outcomes of the research in this thesis. For example, when it was reported by students that "Different cultures took silence to mean different things. Platforms should encourage a response." Was this a requirement of the human-to-human factors in terms of communication or a human-to-computer factor related to system design? Where interpretation may influence, an effort was made to find consensus with students experienced in CSCD or experts who have studied the field of CSCD.

There were some situations where a definitive answer to the phenomenon could not be agreed upon. In these situations, nominalism was an appropriate ontology. This enabled the researcher to put the experiences of teams and observations of experts first, and draw conclusions based upon consensus. Where consensus could not be reached, it was not the end goal. This relates to the generalisability of the outcomes of this thesis. Some similarities could be observed between the studies of the GDP and other global design classes. In these scenarios, the work could be generalised and transferred. However, for other contexts, there may not be an easy comparison and transfer.

3.2.3 Epistemology

Easterby-Smith et al. (2002) defined epistemology as a "General set of assumptions about the best ways of enquiring into the nature of the world". Where ontology considers the nature of reality, epistemology considers the methods of investigating reality, meaning that ontology and epistemology are closely linked. Like ontology, epistemological arguments exist along a spectrum with different world views.

There are two extremes of world views: positivism and social constructivism, and the practical middle ground, relativism. There is a possible change between the two along the spectrum of world views from deductive inquiry to inductive inquiry. The deductive approach of positivism comes from research in the natural sciences and has been established for several hundreds of years, whereas the inductive approach has come from the social sciences and is relatively modern, emerging in the 20th century (Saunders et al. 2000). Where facts are considered to be concrete in positivism, facts are human creations under social constructivism (Easterby-Smith et al. 2002).

Positivism relates to traditional scientific enquiry (Saunders et al. 2000). It supports the world view that the observer of the phenomenon is independent of the phenomenon. In other words, the researcher is separate from the subject of the research they are conducting and does not influence the outcomes of the research. Additionally, human interests in the outcome of the research are irrelevant. Positivism is a deductive method of inquiry (Saunders et al. 2000) and supports deductive research methods best, such as, experimental and survey research.

Social constructivism lies at the other end of the spectrum and is a modern research view. It was mainly developed as a reaction to positivism (Easterby-Smith et al. 2002). Social constructivism presents the theory that the observer is a part of that which is being observed, and that human interests are the primary driver of scientific endeavour (Easterby-Smith et al. 2002). Social constructionism is an inductive method of inquiry where theories are built from observations, supporting methods such as action research and ethnographic research.

Relativism exists within a middle ground between positivism and social constructivism. It supports the relativist view that facts are dependent on viewpoint and consensus

(Easterby-Smith et al. 2002). This viewpoint supports case study research and grounded theory research.

It is essential to note that this is just a sample world views and not representative of all. For example, the interpretivist world view has been increasingly popular in the social sciences and business research (Saunders et al. 2000) that is a further extreme to the social constructionist world view on the spectrum.

Easterby-Smith et al. (2002) highlighted two further world views that have a pragmatic basis. These are relativism content analysis, and grounded analysis. Content analyses have a prior hypothesis that the researcher seeks to prove or disprove, whereas a grounded analysis takes a holistic approach to understand the data's context. While content analysis is objective in approach, grounded analysis is subjective and preserves ambiguity and contradiction (Easterby-Smith et al. 2002). These views are important when considering epistemological views as the presence or absence of a hypothesis defines the research approach.

As the research is based upon observations, there are considerations of whether these are factual or open to interpretation. The way that teams work can provide factual observations about actions that are taken, however, these are not the focus of the investigation. The focus is on the reasons why actions were made and if they support best practice to evaluate and select appropriate technologies for CSCD. The reasons for these decisions made are open to interpretation. In interpreting, the observer is a part of the scientific enquiry, and their interests may influence their observation as suggested in social constructionism.

3.2.4 Methodology

Easterby-Smith et al. (2002) defined the methodology as the "Combination of techniques used to enquire into a specific situation" where techniques are activities used to enquire a phenomenon. When selecting techniques, they must depend on the philosophical worldview outlined, and they can produce what needs to be achieved by the research. Saunders et al. (2000) suggested five essential methods: sampling, secondary data, observation, interviews, and questionnaires, as being fundamental to research enquiry.

Sampling involves collecting data from a general population. That usually takes place alongside another method such as observations, interviews or questioners. Sampling can be systematic or random, but it is essential to justify why this sampling has been selected and not to make any false claims on the results of the data or its implications (Saunders et al. 2000).

Secondary data is that which the researcher has not collected. This can be published data or raw data obtained another way. It could be both quantitative and qualitative in nature. Furthermore, it can be mixed with primary data to analyse a change or compare one phenomenon with another. Unfortunately, this data is challenging to find, and data may not be completely comparable. However, this method is unobtrusive, and there is the potential for considerable generalisable research.

Observations are beneficial if the research question is concerned with what people do. This may be a separated role, or the researcher can participate in the task. Observations can be structured in the form of a task to complete or unstructured in the form of ethnographic research (Saunders et al. 2000).

Interviews are a way to collect valid and reliable data. They can come in many forms but range from structured to unstructured. Interviews tend to be qualitative but can collect quantitative data using closed questions. There is some ambiguity with the reliability of the opinions collected in interviews, but this must be considered when analysing data and generating theories. The competence of the interviewer must also be taken into consideration, especially when asking probing or open questions.

The description of a questionnaire can be varied. Saunders et al. (2000) believe that this method includes any situation where one person asks another the same set of questions, meaning that structured interviews can be considered a questionnaire in some cases. Questionnaires are best suited for large-scale inquiries to collect data from many people and form a consensus within a normal distribution. However, the results of a questionnaire may prompt more significant enquiry for which interviews may be used (Saunders et al. 2000).

To research CSCD, there is a need to utilise appropriate methods that suit the enquiry and the contributors. When teams are forced to conduct a task for research purposes, they will change their behaviour to best suit the task completion. This may not give an accurate representation of how the team actually works. In contrast, observations of teams working in a natural environment will reduce a behaviour change. Observations will be essential for obtaining an accurate understanding of teamwork.

To supplement this observation, there is a need to explore a depth of understanding of decision making and the team members' opinions. This could be achieved by surveys and interviews for both the team members and experts who also have a deep understanding of the phenomenon. Furthermore, there may be a need to prompt deeper thought into observations that workshops can support.

3.3 Research approaches

Easterby-Smith et al. (2002) consider three types of research that can be conducted successfully: pure research, applied research and action research. It is important to note that several more formal research approaches exist, and that these three represent prominent stances along a spectrum.

Pure research represents a highly theoretical stance of which there are no considerations for practical implications of the research. Pure research represents a typical research process of discovery, invention and reflection. The outcomes of this research are in the article's, books and journals for others to learn.

Applied research is focused on providing solutions to problems and is grounded in a practical need. This type of research is often partnered with a client, and it is essential to consider their needs when planning the research. The results of this research are applied and tested and can be reported in practitioner and professional journals when the impact of the results have a wider audience (Easterby-Smith et al. 2002).

Between these two extremes is action research. The term was first used by Lewin (1946) and is described as: "The research needed for social practise can best be characterised as research for social management or social engineering" and popularised this by remarking: "Research that produces nothing but books will not suffice." Action research developed with the best of both world approaches does have are some flaws. One of the issues is the holistic problem of ensuring that research is true and good. Lewin argued that research must be moral and just, but the approach could justify research as flawed and, therefore, false. Action research is popular with business researchers when collaborating with business practitioners to promote change (Saunders et al. 2000). The outcomes of this research are analogous with a business approach where motivation and phenomenon are proposed first, and the knowledge gap confirmed later.

As this research is concerned with the development of a systematic automated method to allow engineering design teams to evaluate and select appropriate technologies for CSCD, this research is involved in providing solutions to problems for which there is a practical need. However, there is also a need to ensure a scientific foundation for this research work that requires discovery, invention and reflection. Therefore, action research is a good fit of both, which enables the development of a practical outcome, based upon scientific discovery, invention, and reflection.

3.4 Research design

This section will detail how the philosophical implications and methods described earlier will be assessed, chosen and applied to this study. As stated by Easterby-Smith et al. (2002): "Research design are about organising research activity, including the collection of data, in ways that are likely to achieve the research aims". It is, therefore, necessary to understand what the design considerations are for each research question. Furthermore, how might different world views affect how the answer to these questions can be found to select the appropriate method. To ensure appropriate research design, Saunders et al. (2000) recommended beginning by understanding the attributes of a research topic and posed a set of questions. These questions and answers that follow are related to the approach for the research detailed in this thesis.

Q1. Is the researcher involved or independent from the research?

First, is it possible for the researcher to remain independent from the research they are conducting? In this case, to investigate all research questions, there must be a considerable amount of involvement by the researcher in collecting data. This action may influence the actions of the design team who are being investigated.

In addition, through data analysis, the researcher will interpret the data with their own worldview, which could have repercussions for the significance of some data sets and the rationale. As the researcher will be working alone on this project, there will be few opportunities to involve the opinions of others on all decisions and interpretations of the data. This interpretation puts the research towards the epistemology of social constructivism.

Q2. Are large or small sample sizes required?

When considering what sample size is required, it is important to first consider the categories of people who should be involved towards the aim. As a variety of opinions are required on engineering design teamwork, data could come from sources such as student with their experiences and reflections, experts with their experiences and reflections and published literature on engineering design teamwork for CSCD and, in particular, technology use.

This research utilises the experiences of the students who took part in the Global Design Project 2015-2019 - the University of Strathclyde and the Global Studio 2016 & 2017 - Loughborough University Design School. In total, 206 students were involved.

Experts in collaborative design were invited to be a part of this research work at three international conference events, the 18th International Conference on Engineering and Product Design Education, the 21st International Conference on Engineering Design and the 15th International Design Conference. Experts were invited to connect through two networks of academic research groups, Collaborative Design Special Interest Group - The Design Society and Design Education Special Interest - The Design Society. In total, 69 experts contributed to the surveys, discussions and workshops.

To compare this sample with the student engineering design teams would be difficult to estimate. However, it can be said that the GDP and the Global Studio are two of three distributed design projects with a partner university in the UK. No other projects were identified in the systematic literature review or were known of otherwise. The other global design projects-based class is the EGPR, which has the partner University of City University London. The EGPR class does not have a direct relation to the research but may benefit from the outcomes. This research only claims to represent the knowledge of the students and experts involved, but there may be lessons to be learned for other related classes.

These students were involved in a global design project, mainly masters level students, and mainly based at a UK institution. Variables such as culture (Tonso 2006; Vance et al. 2015), time (Vance et al. 2015; Lauche & Bohemia 2007), background (Oladiran et al. 2011; Malheiro et al. 2015) and context (Ocker et al. 2009; Gibson & Cohen 2004; Singh et al. 2013) will all have an impact on the outcomes of the research and suitability of the outcomes for other scenarios.

The research took place between 2015 and 2019. If the research had taken place a decade earlier; the technology used would have been different, internet capabilities would have been less due to lack of lower infrastructure capabilities, and these factors would have impacted attitudes towards global collaboration using these types of technologies. However, there are some generalisations that can be made related to the experiences of these students and experts. Where the similarities exist, the work can be generalised to fit similar contexts e.g., other global design projects and other design contexts related to technology use.

Q3. Does the theory or data take precedence?

The research questions are phrased to encourage exploration of the research problem. Strauss (1987) presented a view of a grounded theory that fits with the potential exploration required to support the researcher's involvement and the sample sizes required.

It is vital to have a subjective stance observing behaviour, interpreting and sharing the researcher's theories for a grounded research approach. However, it is important to note that it can be expected that the researcher has some prior knowledge or preconceptions that they might apply to their observations or interpretations. Research Questions were chosen over hypothesis as the research question is an investigatory statement and not worded as a statement that can be proved or disproved.

Q4. Is experimental design (closed enquiry) or fieldwork most appropriate (open enquiry)?

To best answer the research questions in the context of engineering design team projects, there are research methods of inquiry that could investigate experimentally within a confined setup, or observe team working naturally. There is a need to consider if a team member would change their behaviour because they are being studied under certain conditions, or if an artificial experimental setup is used, if the team members would behave normally as a team.

As this research focused on the inquiry into a phenomenon that is already happening, i.e., students involved in global design classes, this study aimed to investigate *how* this occurs. Students are using technology, and there is a need to establish what technology is being used and why it is chosen, which are questions with a factual inquiry. To understand how the functionality of technology that supports CSCD, there is a need to investigate a team holistically. A mixed-methods approach is most appropriate.

This research will require a gathering of quantitative and qualitative data methods to gain a complete understanding. Glasser & Strauss (2000) claimed that "in many instances, both forms of data are necessary… whatever the primacy of emphasis" that both experimental design and fieldwork are appropriate, and decision making should be directed by the enquiry.

Q5. Is Universal theory or local knowledge appropriate?

This research was based upon a foundation of research and theory on teamwork, technology use and CSCD within an educational environment from literature searching and expert's input. To best understand technology use in teams, there was a need to expand the enquiry to more generalised knowledge beyond engineering design teams within an educational environment ensuring all potential inputs were considered. However, to understand technology use in the study's time frame, towards the users the research aimed to support and within an educational context, there is a need for specific local knowledge to be used.

Considering the cycle of research modes of enquiry from *specific idea to general phenomenon* using deductive modes of enquiry, or from *general phenomenon to specific idea* using an inductive mode of enquiry, the research within this thesis is inductive in nature as it utilises generalised phenomenon reported in the literature (requirements of CSCD) to produce a specific idea (CSCD matrix tool/evaluation and selection method).

Q6. Verification or falsification?

The research questions specified have been designed to guide the scientific enquiry, evaluate the research that has taken place and support the assessment of value of the outcomes. Each research question relates to the aims and objectives of the research, and evaluation can occur if the research questions have been proven to be true or false.

For RQ1. as an example, the research question asks, '*Can a systematic automated method be established…'*. This opens the discussion if a method is possible, and what this method might look like. This supports exploration towards a practical solution that allows the evaluation and selection of CSCD technologies.

When choosing methods of exploration, it is important to determine if verification or falsification is then required. This was important for the evaluation of the CSCD matrix method using the GDP class data. It can be verified that the method has worked as intended, and that the results of the data could be used in an intended way so that a method could be established.

3.5 Selected research design

By answering the questions set by Saunders et al. (2000), considerations for an appropriate research design were investigated, and the research design was selected. Based upon Q4 in Chapter 3.5, data collection based upon a mixture of quantitative and qualitative methods is required. There is a need to investigate experimentally within a controlled experimental setup and observe teams working in a natural environment. In addition, based upon the answer to Q1 (Is the researcher involved or independent from the research?) in Chapter 3.5, the researcher will impact the results because of the effects of observation and interpretation of the data.

The nature of the data collected was a mixture of quantitative data (concerning the use of technology), metadata on the functionality used, and opinions on the requirements of CSCD directly from team members experts and academic papers. This nature means the researcher needs to be involved with the data collection (involved) and interpreting the data (social constructivism).

Easterby-Smith et al. (2002) provided an example of typical research designs mapped in a matrix of epistemology against ontology (Figure 3-1) to provide examples of common research designs. This research lies between social constructionist and involved due to interpretation of the outcomes. The most appropriate research design as illustrated in Figure 3-1 would be Strauss definition of grounded research, provided in Chapter 3.5. This identification helps to position the research work with other research projects, to compare methods and outcomes and provide the rationale for the author's research assumptions that interpretation and influence of the data are possible.

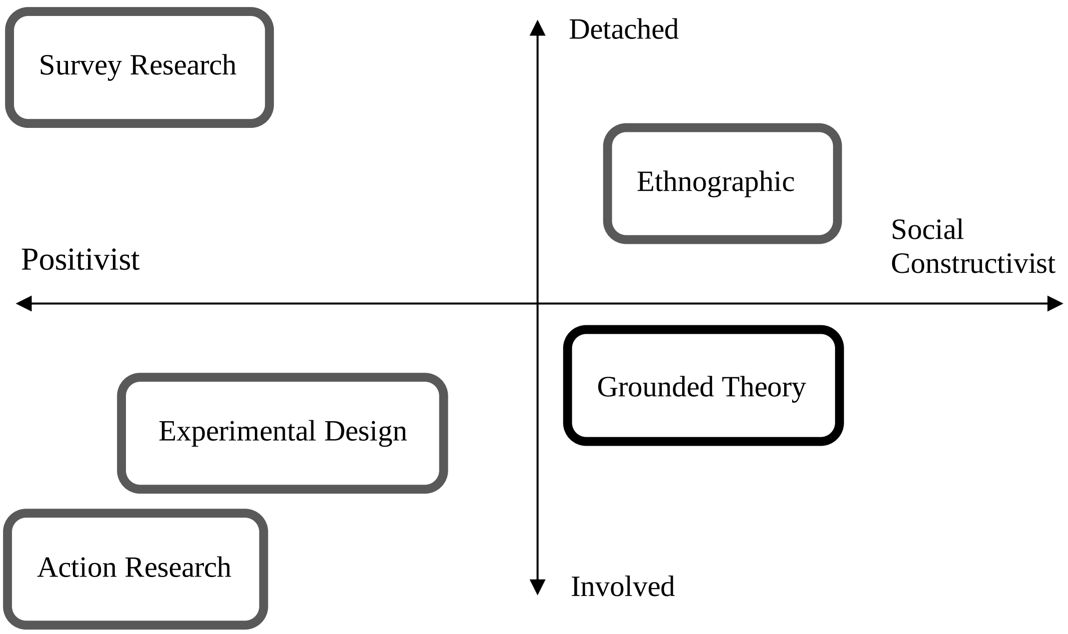

Figure 3-1: Matrix of research designs. Adapted from Easterby-Smith et al. (2002)

From a constructionist viewpoint, there are three questions to ensure validity with every study, as Easterby-Smith et al. (2002) suggested. Firstly, the study must gain access to those in the research setting. This research aims to represent the views of the students, academics and experts involved in CSCD. Generalisations may be possible to the broader distributed engineering design community. Secondly, there needs to be 'transparency' in how data was interpreted. This was achieved through documentation and inter-coder analysis of the data using multiple coders, detailed rationale for the process, and the voice of the author to explain the interpretation in their world view. Finally, the results can only be confidently applied within its own context (CSCD), that is, the work is related to technology use within collaborative engineering design teams in an educational environment. There may be scope to generalise the results for a wider audience if the context is similar. While there may be similarities between this research and other research of a related context, the similarities are clearly described, and the method developed for the creation of the CSCD matrix so that appropriate knowledge transformation can occur.

3.6 Research approach map

To ensure the completion of the research aim in a scientific way, a research approach map was established. The purpose of the map is to display the logical structure of the research activities conducted, and the knowledge contribution. The map illustrates the variety of research sources used, and how the activities and research sources provide input to the knowledge contribution. Towards the research aim, there were many secondary contributions to the knowledge required to realise the method of building the CSCD matrix and the primary contribution to knowledge. These are all displayed in the research approach map (Figure 3-2) as a flow chart.

The main contribution to knowledge was to develop a systematic automated method to allow engineering design teams to evaluate and select suitable technologies to support CSCD. This automated method of evaluating and selecting suitable technologies will later be referred to in this thesis as the 'CSCD matrix'. The CSCD matrix is identified in Figure 3-2 as the primary contribution to knowledge.

To achieve this primary contribution to knowledge, there were many research activities and knowledge-building activities. Building knowledge through established sources using a literature review contributed to understanding the requirements of CSCD, knowledge of evaluation matrices, and knowledge of the functionalities of technologies.

The literature on CSCD requirements was not directly applicable for use within the CSCD matrix: there was a need to construct this knowledge and format it in an appropriate way for use within the CSCD matrix. This requires several research activities and knowledge-building activities, including systematic literature search, literature review, categorisation of requirements, development of the E2 design activity model with the factors which influence CSCD. During this process, at the categorisation of requirements, there was a need to rely on the existing research from the literature and collect and build upon the knowledge of CSCD experts through a survey and workshops. This ensured that the knowledge from the literature was appropriate and that the theories on requirements were based upon the expertise of the wider community.

Upon establishing the evaluation and selection method as the primary contribution to knowledge, there was a need to establish the value of the contribution to knowledge and evaluate its significance as is important for research to achieve a PhD.

The demonstration of the method functioning as designed using data from the GDP 2018 to produce a populated CSCD matrix confirms its success from a functional view. The contribution to knowledge is the method produced that has been successfully demonstrated. Further contributions to knowledge are the requirements of CSCD, and the development of educational aspects related to the CSCD matrix. Value is established in the feedback from experts and students on the use of the method and education it brings. This also represents the significance from an educational point of view.

From an academic point of view, significance is verified by impact on the community. The method and its creation have been accepted by the community as published in (Brisco, R. Whitfield, et al. 2019) and the involvement of community in the development of the requirements of CSCD in workshops and surveys. The significance of this research continues as interest in the method for other educational/academic contexts and for industry.

Validation of the CSCD matrix was conducted by applying the CSCD matrix in a practical application to analyse the GDP 2018 and demonstrate that the method is appropriate for technology evaluation and selection within the context of the class. This was built upon the knowledge of the requirements of CSCD (Chapter 5), the guidance of success in team projects and knowledge of the available technologies (Chapter 2). These knowledge-building activities were conducted within the GDP, GS and the workshops held at conferences. This knowledge was based upon ethnographic research of three kinds, academic and student workshops, field research, supporting the GDP as a mentor for several years and keeping diaries on team member behaviour, and student reports where they explicitly reported upon the challenges of CSCD within the GDP. Based upon this knowledge building to support the validation, the strengths and weaknesses of the CSCD matrix could be discussed.

All research activities and outcomes originate from data sources. These sources represent a mixture of different methods and research approaches as required to investigate the aim. The sources discussed in this chapter and selected based upon epistemological and ontological assumptions. Figure 3-2 displays a logical structure for the research. Within this figure there are four different types of connection between activities, knowledge sources and contributions being, *based on, derived from, verified by and validated by*. The “based on” interconnection represents a knowledge transformation activity that has taken data and transformed it typically in response to a research objective, these activities were usually created by the researcher. “Derived from” represents a research activity usually created through consultation or workshops. “Verified by” and “Validated by” are used to reflect the evaluation of the research work.

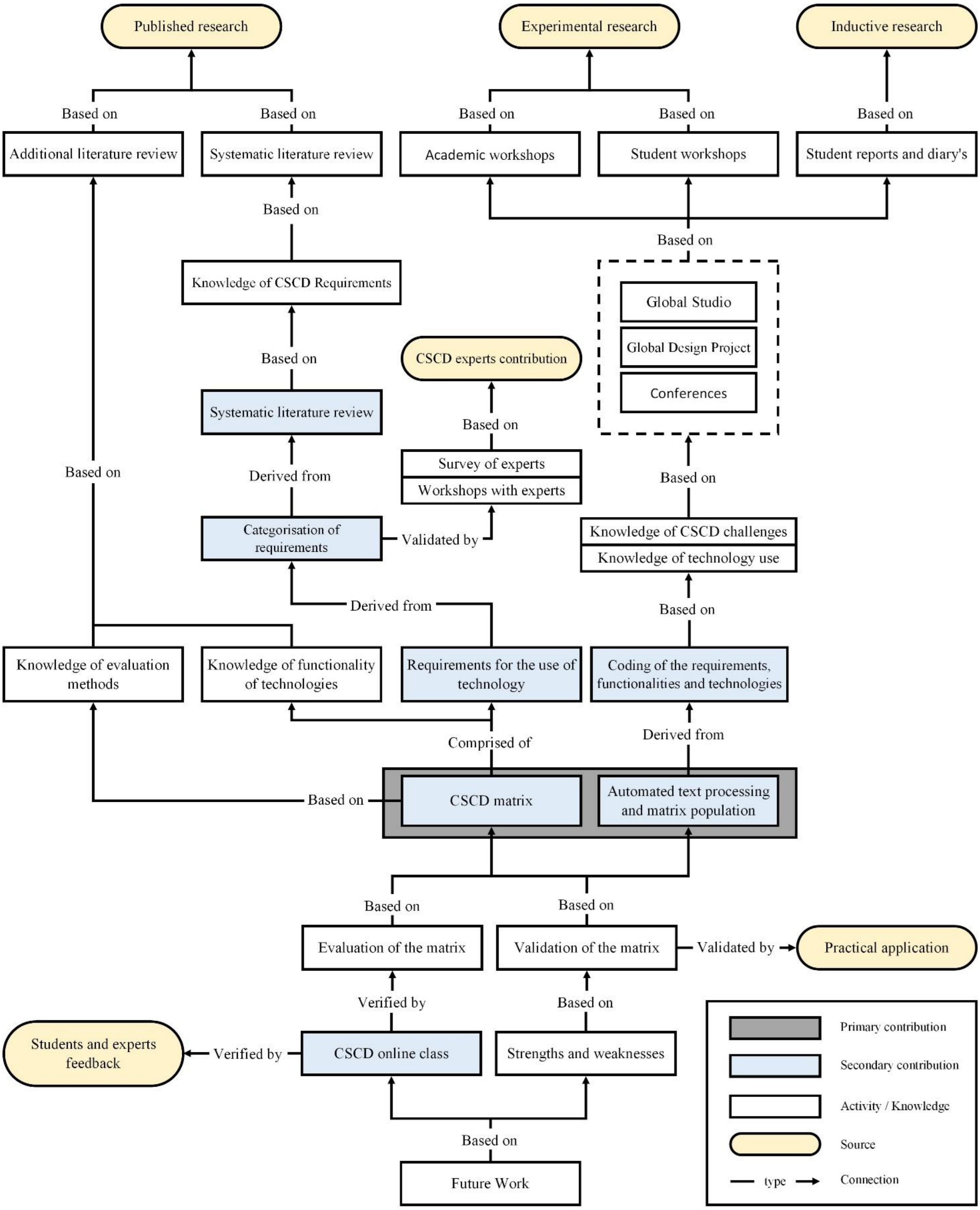

Figure 3-2: Research Approach Map

3.7 Summary

In this chapter, the research approach is detailed, revealing the steps to achieve the aims and objectives of the project. This approach was selected based on the established philosophical and ontological underpinnings, the desired outcomes of the project, and the requirement on the assessment to make a significant contribution to knowledge. This chapter summarises the selection of the research approach.

An investigation into 'what makes a good research approach' was explored, which revealed that there are primarily practical constraints to research, and there should be a consideration as to what is achievable. In addition, there was a need to consider how theory-building plays a vital role in the research approach and that the research should have value.

Research questions were established to support the selection of research approaches that meet the aim. These questions ensure that the primary contribution to knowledge being *'the method'* is achieved through secondary knowledge contributions and research activities.

The nature of the research was explored by understanding the investigation context' engineering design teams', which determines the suitability of the investigation techniques concerning paradigm, ontology, epistemology, and methodology. By specifying the relationship between the research and each of these considerations, ensures that the work remains consistent. A research approach was established based upon these considerations with further details by exploring the specific research design.

A research design was established based on the considerations explored within this chapter. The consideration led to a that aligns with Strauss's description of Grounded Theory. This is the selected research design that supports the development of the research methodology consistently and comparably.

By including the research approach chapter and discussing the philosophical and ontological considerations within this thesis, the academic contribution is appropriately explained to support the research outcomes.

4 LITERATURE SEARCH AND REVIEW

The purpose of the literature review is to critically examine published literature, identify a knowledge gap, and establish the research that can be used as a foundation for filling the knowledge gap. This literature review is written in the form of a narrative review (rather than evaluative, exploratory or instrumental) to position the research within existing work, identify patterns and trends in the literature and to support the identification of gaps in the body of knowledge.

The objective of the literature review was to establish the necessity for a tool that supports engineering design teams in evaluating and selecting appropriate technologies for CSCD using a systematic and automated method, towards the research aim.

The literature review began with searching and collecting published literature, which is then critically read, and a review is formed. A summary of the literature searches, their procedure and their outcomes is included in Figure 4-1.

The literature searches were not conducted in isolation from each other. The scoping search and the state-of-the-art search influenced the systematic literature search the technology use search and the technology functionality search. The systematic search also influenced the collection of literature towards the technology use search and the technology functionality search. The scoping search and the state-of-the-art search also influenced the evaluation and selection methods search in addition to a focused search on this topic.

Literature was acquired in a variety of modes throughout the literature search procedure. The different types of search are listed below with their contribution to the research. Further information on each of the searches is included within the sections that follow.

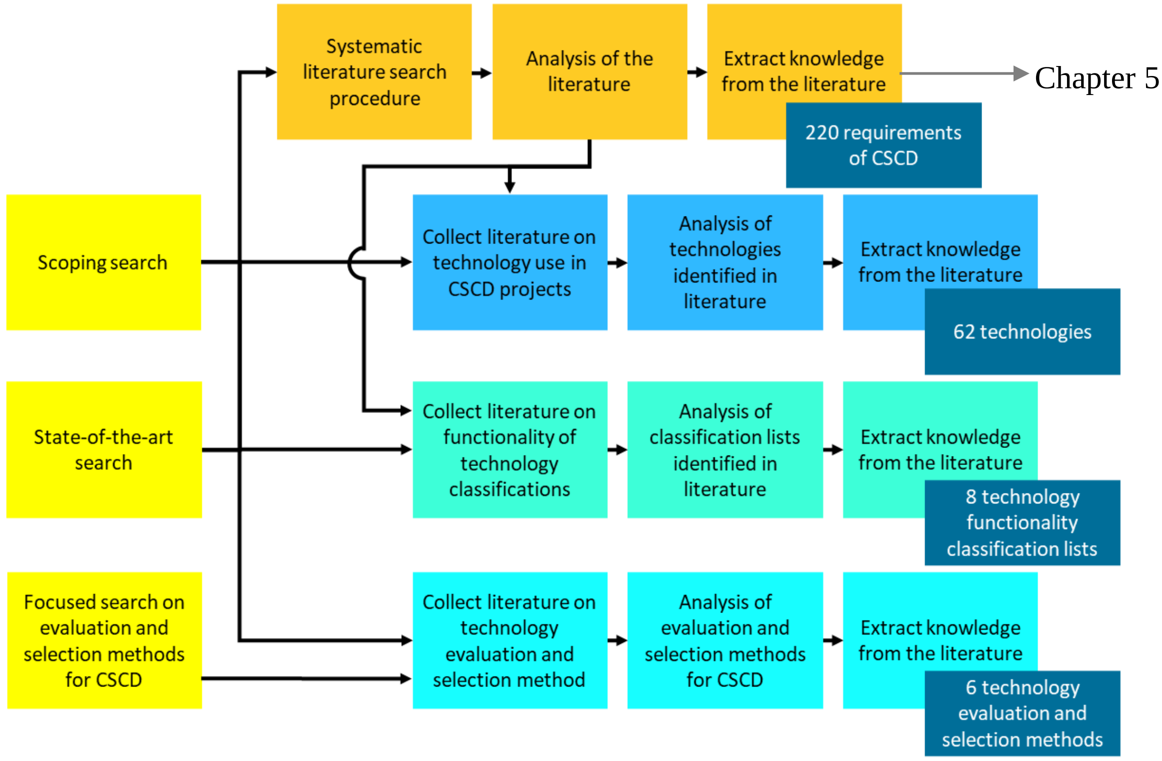

Figure 4-1: Map of literature searches conducted.

i. Initial literature was found from a scoping search to identify key authors within the research area, to conduct preliminary assessment of the size and scope of the literature and to identify the nature and extent of research evidence. The methods used for this literature search were: keyword searching; retrospective searching; and, citation searching. This form of searching was useful in building the researchers understanding of the body of knowledge. The information gained from this search was included in Chapter 1 to provide contextual information of the subject area. This search contributed towards informing the formation of further searches.

   The initial scoping literature search influenced the systematic literature search procedure, the process of collecting literature on technologies used as identified in the literature and classifications technology search as identified in the literature. The initial literature search influenced all parts of the literature search procedure to identify relevant academic search engines towards the aim, identify key work published in the literature, and identify research methods that have been successful for conducting the work in the research area.

ii. A state-of-the-art search was conducted to identify new papers and emerging research as the research progressed. The methods for this literature search included: keyword searching; and, passive searching relying on both notifications and alerts of new papers. This mode of searching ensured that the researcher was aware of the latest publications within the body of knowledge. This knowledge also contributed to Chapter 1 to provide contextual information and informed the formation of further searches.

    The state-of-the-art search was crucial in ensuring that the latest knowledge was being included as the research progressed. A PhD is conducted over an extended period of time, and from beginning to end, there can be crucial new research that influences the research progression. This review took the latest information from published journals, conferences and the latest books to ensure that the research was appropriately informed.

iii. A systematic literature search was conducted to identify requirements of CSCD that was comprehensive and ensured this search could be replicated. This mode of searching ensured that for the search terms used, the researcher had investigated all relevant publications systematically within a select body of knowledge according to criteria. This is further discussed with the procedure for conducting this search in Chapter 4.1.

    The systematic literature search was an extensive literature search procedure and ensured a methodical and robust searching of the literature within the context defined later in this chapter. The literature found related to knowledge of the factors that influence CSCD, technologies used in CSCD projects, and technology functionalities classifications. Where these papers were found which related to technologies or technology functionalities, they were included within the collected literature for these purposes, as displayed in Figure 4-1.

iv. A focused search was conducted to identify evaluation and selection methods which could be used for CSCD. The focused search utilised focused keywords to find papers specifically on technology evaluation and selection methods for CSCD this is further described in Chapter 4.4. The purpose was to confirm the gap in knowledge, and once confirmed to learn from the successful technology evaluation and selection methods that had been developed for similar contexts and purposes.

The scoping search was conducted to build a basis of knowledge in the research area. The keywords used for this search were engineering design teams, technology selection, technology evaluation and CSCD. Over time and through building knowledge of the research in the field, further published research was found gradually. For example, *CSCD in engineering design teams* could be referred to as distributed design teams, global design teams and other related terms. The author collected these terms to inform a systematic literature search detailed in Chapter 4.1.

Throughout the research, academic search engines were used to actively search and notify when new papers were published or became accessible. This mode of search is referred to as the state-of-the-art search. Search engines used for both the initial literature search and the state-of-the-art search were ProQuest, Engineering Village, IEEE Xplore, Scopus and Google Scholar. The first four search engines were selected because of their engineering database, and Google Scholar was selected for its wide-reaching scope and notification abilities to collect state-of-the-art papers. As papers were discovered, they were added to a library using literature management software Qiqqa (qiqqa.com). At the time of writing (April 2021), the general library that contains these papers stands at 3488 papers.

From this general literature search, a systematic search was developed that supported the demonstration of the knowledge gap, that is, a need for a novel automated method of technology evaluation and selection. It was important that this systematic search contributed towards the objective of the research to define the requirements of CSCD.

4.1 Identifying requirements of CSCD from published literature

To achieve the research aim of supporting engineering design teams to conduct CSCD, the requirements of CSCD must be established. From the initial search, it was identified that recommendations of successful practices in CSCD, benefits of using particular technologies over others reported, barriers that exist and opportunities for further development of technologies were reported in the literature both historically and in modern times.

Mattessich & Monsey (1992) first published a list of requirements for co-located collaboration based on published literature. 133 studies were considered by Mattessich & Monsey, and after analysis, 18 studies remained. 19 individual factors were identified across six categories: environment, membership, process/structure, communication, purpose, and resource.

The individual factors identified were:

- History of collaboration or cooperation in the community,
- Collaborative group is seen as a leader in the community,
- Political/social climate favourable,
- Mutual respect,
- Understanding and trust,
- Appropriate cross-section of members,
- Members see collaboration as in their self-interest,
- Ability to compromise,
- Members share a stake in both process and outcome,
- Multiple layers of decision making,
- Flexibility,
- Development of clear roles and policy guidance,
- Adaptability,
- Open and frequent communication,
- Established informal and formal communication links,
- Concrete, attainable goals and objectives,
- Shared vision,
- Unique purpose, and
- Sufficient funds and skilled convener.

Whilst many of these factors are relevant to collaboration today in a computer-supported context, others may not hold the same significance in findings. Certainly, human-to-human factors are prevalent in collocated collaboration and in CSCD. However, the significance of their influence may have changed over time or may have been overcome by technology functionality completely. On the contrary, technology may have created more issues for CSCD teams that were not present in 1992, particularly those with issues between computer and human interaction.

Mattessich & Monsey (1992) investigated the principles for collocated collaboration but did not consider CSCD directly, perhaps due to the maturity of collaborative technology and the prevalence of technology in general in 1992. To determine if the list presented by Mattessich & Monsey, or any other lists by authors are suitable for evaluating CSCD activities of engineering design teams, further investigation is required. To determine the suitability, the requirements of CSCD need to be determined to identify if the requirements align with the categorisation.

Alternatively, A list of categorised requirements may have been created for the specific purpose of evaluation and selection of CSCD technologies within the context of design teams, aligning with the aim of the research.

In addition, since the creation of the list by Mattessich & Monsey in 1992, there may be a substantial change in collaboration theory such that modern CSCD is not relatable to collocated collaboration in 1992. It may not simply be the lack of inclusion of CSCD technology towards building the theory, but also the developments of theory over time that have changed. Therefore, a categorisation of requirements should be state-of-the-art and applicable to today's CSCD work.

There have been several attempts to create similar categorisations of requirements to support different aspects of collaboration within engineering design, including cross-cultural factors (Markus et al. 2007), risk management (van Grinsven & de Vreede 2002), product development (Elfving 2007), agile product development (Reich et al. 1999), and integration of CAD/CAE environments (Maier et al. 2009). Each of these aspects may have lessons applicable to CSCD teamwork. However, as they do not support the aim directly and explicitly, their applicability to a CSCD context should be assessed. The categorisation of CSCD requirements within these publications may have similarities with each other but are built on different theories because of the nature of the collaborative work being different from CSCD. For example, cultural factors are human-to-human concerns and are unlikely to relate to the human-to-technological factors of CSCD, Also CAD/CAE environments may not present a full understanding of collaboration in terms of communications technology, data storage technology which are present in CSCD.

Typically, the work in the research area is not regularly updated and is applicable towards a specific time period. As theories of collaboration evolve and technologies change, the list of requirements will also change. For work in this field to remain relevant, it must be updatable with relevant information on the method of creation and reflection on how the outcomes of research can be updated in a managed way.

With these considerations, the methodology of the systematic literature search to identify the requirements of CSCD was established.

4.1.1 Methodology to identify the requirements of CSCD

To identify the requirements to support CSCD from the literature, a literature review approach was created. First, a definition of the boundaries of the systematic literature review was created (Figure 4-2 – Step 1) followed by the creation of a search procedure as influenced by the PRISMA guidance (Figure 4-2 – Step 2). Scoping searching and the state-of-the-art search influenced the development of an iterative literature search approach towards a preliminary search to establish the relevant search engines and the search string (Figure 4-2 – Step 3-5). Once established, the full search was conducted, and relevant papers were downloaded and analysed against the exclusion criteria (Figure 4-2 – Step 6-9). 27 papers were found with 220 findings. The findings were finally extracted and consolidated from the literature (Figure 4-2 – Step 10).

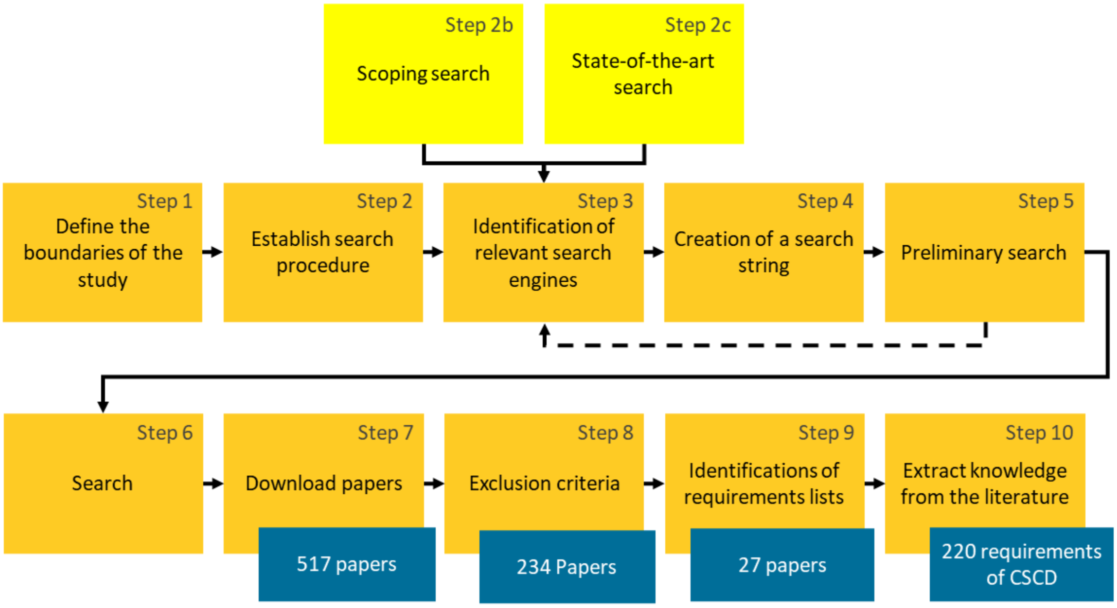

Figure 4-2: Methodology to identify the requirements to support CSCD

4.1.2 CSCD within the boundaries of the study

It was apparent that a literature search could be extended to the first reported use of technology to support collaborative design published in the literature, but it was unclear if these reports would be relevant to this investigation. The first example of technology use within a work environment was detailed by Johansen (1988) where Stanford University researchers developed the first computer instant messenger system in 1967. The system was envisaged to allow business gatekeepers the ability to communicate using instant text messages for business purposes. Instant messengers today enable text communication for the same outcome. However, the technology is dramatically different. In 1967 the instant messenger system did not have the same functionalities that modern systems have including; metadata (message timestamps, tagging), enhanced HTML formatting, enhanced media (image/document) sharing or notifications. In addition, the availability of technologies and the context in how they were used has changed significantly. In 1967, powerful computers of the time were required to demonstrate text communication in lab conditions. Now, even our typical lowest powered mobile devices can send and receive text communication over wireless networks. This is a prominent example, but is employed to explain that technology capabilities and usability change dramatically over time. Because of this, a time frame for the study is important to define to ensure the systematic literature review captures relevant and timely research.

During the iteration of the preliminary search to identify relevant search engines and create a search string (Figure 4-2 – Step 3-5), there were many papers that were identified as being relevant to conducting CSCD in the context of engineering design. Some of these papers were identified as less relevant to this research due to similar reasons as to why the outcomes documented in Johansen (1988) are less relevant to today's technology functionality and technology use context. Over time, even for a shorter time such as 4 years as indicated by the preliminary study (Chapter 2.2), the technologies, processes, and procedures reported become increasingly less relevant. Conole & Alevizou (2010) identified that Web 2.0 technologies did not achieve maturity until 2010, which draws into question if technologies developed before 2010 were relevant to the state-of-the-art technologies during this research period (2015 - 2020).

Conole & Alevizou (2010) stated: "We have seen a continual evolution of technologies and how they are used […] and we are only beginning to develop an understanding of what the trajectory of this co-evolution will be." This opinion raises the challenge of maintaining the relevance of the requirements of CSCD as a solution for selection in the future. To ensure relevance, the list of requirements of CSCD should be updated to align with purpose and time, and support key advances of the capabilities of technologies.

When it is determined that the requirements have changed, they can be updated with relevant requirements using the same approach.

Another motivator to limit the technologies included within a specific time frame was related to the motivation of the research in Chapter 1. There was an observable change in the students' decision to use social network sites and mobile devices within the GDP class around 2010 – 2015 coinciding with a change in social behaviour driven by the spread of social websites. In 2010 Facebook reached its position as one of the top five websites by user traffic in the USA (Metrix 2010; Post 2014). This social change encouraged the spawn of other social network sites and a trend towards mobile social network sites with the proliferation of smartphones over feature phones in the USA in 2010 (Butler 2010). There was also a notable increase in the number of social business support technologies coming to the market around this time.

For these reasons, the year 2010 was decided as the cut off to ensure studies into the requirements of CSCD would be relevant to the state-of-the-art technologies as currently used by students.

Exclusion criteria one was established as 'data collected before 2010 is excluded'. This exclusion was applied to the search engine by limiting the search to papers to publishing from 2010 onwards and during the search of the results based on the date in which data was collected.

The boundaries of the study were defined with respect to four aspects that aligned with the aim of the research and motivation of the research project:

- Within the research domain of engineering design;
- Relating to collaborative design within a team setting, requiring collocated or distributed interactions;
- Supported by computer technology; and,
- Research from 2010 onwards to support state-of-the-art.
- The implementation of these boundaries is further discussed in Chapter 4.1.3.

4.1.3 Search procedure

A systematic literature search was identified as a suitable method to identify the requirements for CSCD from the published literature. This literature search is suitable for identifying what is known, recommendations for practice, and identification of limitations (Grant & Booth 2009). In comparison, a typical literature search may not include comprehensive searching or quality. Grant & Booth (2009) state that a systematic search and review "Combines strengths of critical review with a comprehensive search process. Typically addresses broad questions to produce 'best evidence' synthesis". The focus is on the practicalities of synthesising knowledge from multiple sources in a robust way rather than the narrative.

To ensure a robust literature search procedure was followed, guidelines were adapted from Moher et al. (2009) on *Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)*. PRISMA ensured a systematic collection and recording of literature as required for a systematic search process. The procedure is the identification of records from databases and screening to remove duplicates, ineligible records, or other reasons of exclusion. At each stage, the records were screened and the included and excluded search results were recorded. The PRISMA guidelines were adapted by removing the meta-analysis stage required in medical studies, but the statistical synthesis was not required for a systematic literature search using the data recorded. All other parts, including protocol search, eligibility, identification of information sources, search, data processing and exclusions, and synthesis of results, were retained.

PRISMA guidance includes the use of search exclusion criteria. Suggested exclusion criteria were established as non-accessible papers, non-English papers, non-peer-reviewed, and all duplicate papers. All these exclusion criteria were applied in the systematic literature search. The language was restricted to English and peer-reviewed papers on each search engine. Access to individual papers and duplicate papers were filtered after the search during the analysis of results.

A preliminary literature search was conducted to understand the possible outcomes of such a search, literature before establishing the criteria for the systematic literature search. It differs from the systematic literature search, that follows in that it was used to establish the search parameters for this search iteratively.

Two types of assessment were conducted: papers were explored from academic search engines by exploratory keyword searching and recording the success of keywords in finding results. These papers were also explored for referenced papers or recommended papers, and keywords were collected. These keywords then influenced the exploratory keyword searching, and the cycle continued. During the preliminary search, keywords and source of the papers were recorded to quickly find the paper again if required. This created the preliminary search string and the list of search engines used for the systematic literature search as detailed in Chapters 4.1.4 and 4.1.5.

A search question was created to guide the systematic literature search and to support the evaluation of relevant papers: “What are the factors which contribute towards CSCD in engineering design teams?” The term ‘factors’ was used rather than ‘requirements’ since the term factors relate to the alternative ways the authors of papers in the literature were able to document findings about CSCD related to opportunities, barriers, and benefits of teamwork practice.

If a paper was found in the preliminary search that could contribute towards answering this question, the keywords used to find it were included within the systematic literature search. Exclusion criteria three was set that required explicit statements of factors which contribute towards the success of CSCD projects. For example, a paper that lists the recommendations for CSCD projects or lists the barriers/opportunities/benefits of CSCD teamwork.

The three exclusion criteria established for the systematic literature search as defined by the boundaries of the study were:

i. Data collected before 2010 was excluded,
ii. Non-accessible, non-English papers, non-peer-reviewed and all duplicate papers are excluded,
iii. Papers that do not report explicit findings or statements of factors that contribute towards CSCD projects.

Covidence was used to support the critical reading of papers, which provided support for systematic reviews by allowing papers to be annotated, categorised, and identified duplicated papers.

4.1.4 Identification of relevant search engines

A literature search (Step 3 in Figure 4-2) for both the preliminary search and the systematic literature search was conducted using academic search engines. These search engines were used to identify literature relevant to the search questions. The following considerations influenced the choice in relation to the search engines:

- All academic search engines should relate to the research domain of engineering design, including within an educational environment;
- All search engines should index papers relating to design within a team context;
- All search engines should index papers relating to computer-supported collaborative design; and,
- All search engines must support Boolean search functionality.

Academic search engines included those recommended by the Strathclyde University Library for studies in engineering fields. In addition, EBSCO was added during the preliminary search, to include papers published in education journals and conferences related to engineering design teamwork. This supported the purpose of the systematic literature search with, albeit, a smaller number of paper that were highly relevant to the educational aim of the research.

The relevance of the search engines was assessed iteratively using the initial searches. If new relevant papers were identified, then the search engine was included. A full list of the search engines that were used during the search is included as Table 4-1.

Table 4-1: Search engines used in the study and their relevance

Search Engine	Database - Topic
Proquest	All databases – Engineering amongst others
Engineering Village	Compendex – Engineering
IEEE Xplore	All – Computer-supported and technological
Scopus	All – Science and technology amongst others
EBSCO	All - Education
ACM Digital	Full-text collection – Computing

4.1.5 Creation of the search string

The search string was created during the preliminary literature search (Figure 4-2 Step 4) to ensure consistency across all search engines within the boundaries of the study. The search string was created iteratively alongside the identification of relevant search engines based on the preliminary literature search. Synonyms were tested during the preliminary literature search, and if successful in identifying new relevant papers, they were included in the updated search string and retested. Within the boundaries of the study, the search terms used within the search string had three considerations related to:

- The technology of computer-supported use;
- The research field of collaborative design within a team setting; and,
- The research domain of engineering design.

The research was considered to be relevant to the study if it could satisfy the three considerations within the text, title, keywords, or abstract. The synonyms were defined in accordance with the categories as displayed in Table 4-2 and the Boolean search string created to represent the search string.

Table 4-2: Search synonyms across categories

Technology		Field		Domain
Computer W/1 Supported		"Collaborative Design"		Engineering N/1 Design
Social W/1 Network		"Design Teamwork"		"Product Design"
Social W/1 Software		"Cooperative Design"		"Industrial Design"
Mobile W/1 Device	AND		AND	"Design Studies"
Mobile W/1 Phone				
Smart W/1 Phone				
Tablet W/1 Computer				
OR		OR		OR

The synonyms were linked using an OR command and categories connected using a AND command, for example; (Computer W/1 Supported OR Social W/1 Network etc.) AND (Collaborative OR Design Teamwork etc.) AND (Engineering N/1 Design OR Product Design OR Industrial Design etc.). OR commands ensure anything with the categories is included within the result, whilst AND commands ensure all results have at least one search term from each column.

Boolean commands W/1 and N/1 were employed to find words near each other but perhaps not directly next to each other. The command W/1 was used for terms such as "mobile device" where a word may be used between the two terms, e.g. "mobile *communications* device". The command N/1 was used where terms could be near each other but not within a specific order, such as, "engineering design" or "design engineering" or "engineering product design".

Two search procedures were conducted depending on the academic search engine functionality. For all engines excluding ACM digital library, searches were entered into the basic search box on the search page using the OR Boolean operation for each category (e.g. Computer W/1 Supported OR Social W/1 Network …). Once all results were returned, search results were combined using the recent searches page using the *AND* Boolean operator (e.g. Search 1 OR Search 2 OR Search 3). When searching on the ACM Digital library, changes were made to the way the search was submitted to the search engine due to the restrictions of this search engine. The ACM digital library does not allow searches to be combined once completed, so the full search string was used once.

4.1.6 Conducting the search, exclusion and extracting the factors that support CSCD

The full and final search was conducted in June 2017, and the results were used to form the systematic literature review. The state-of-the-art review detailed previously ensures that the researcher was aware of any new and relevant research published.

The systematic literature search revealed 517 papers that met the search criteria across all search engines. A full breakdown of results per search engine is included in Table 4-3. RIS format metadata was downloaded from each search engine, including title, abstract, author, year, and publication details. In addition to the metadata, a copy of the full paper in PDF was downloaded.

The systematic literature search is referred to as version seven, this is because six iterative versions of the preliminary search were conducted before the keywords and search engine inclusion met the purpose of the systematic literature review towards the overall aim of the research. The researcher was satisfied with the search outcomes when there were few differences in outcome between versions of the search, meaning that an appropriate saturation point was achieved and all relevant papers were captured. A balance had to be reached in terms of the keyword led search. A systematic review would follow a systematic procedure as detailed within this chapter. Practically this means that some papers may appear to be relevant due to the keywords used, however, they are not relevant to the study in terms of theme, research field or other aspects of the paper that align with the aim of the research. These papers may be suitable for the general knowledge building of the author, but are not suitable towards the identification of technology of computer-supported use, relating to the research field of collaborative design within a team setting or relating to the research domain of engineering design.

At an early stage, it was noticed that papers from the field of fashion/garment design were collected within the 517 and when efforts were made to exclude these papers on search engines, they would also remove some relevant papers on engineering design. This was due to the keywords used of product design, industrial design and design studies. It was determined from examining these papers, that some research may be applicable for the purpose of the literature review in terms of the global collaboration aspects that they discuss, and so it was decided that these papers would be collected, and a thematic exclusion and inclusion criteria would be created to determine the inclusion of these papers based upon the metadata of the paper.

Table 4-3: Search engines used in the study and the number of results they produced.

Search engine	Number of results
Proquest	149
Engineering Village	25
IEEE Xplore	187
Scopus	23
EBSCO	7
ACM Digital	126
Total	517

Exclusion criteria was applied to all 517 papers in order to reduce the total number of papers. Exclusion criteria one (Data collected before 2010) was ensured by limiting the year of papers included within the search outcomes on the search engine themselves. Any papers published in 2009 or earlier were excluded as stated in Chapter 4.1.2.

This exclusion criterion did not remove papers that had data captured before 2010 but were published in subsequent years. Through analysis of the papers it was determined that five papers had data from before 2010 and these were manually removed.

Exclusion criteria two (Non-accessible, non-English papers, non-peer-reviewed and all duplicate papers) were partially removed by the search engines but checked by the reviewer using Covidence. All papers were confirmed to be accessible, in English and peer-reviewed from the first analysis. 35 papers were removed because they were duplicates leaving 477 papers.

Exclusion criteria three was applied in two steps. The first part was to use the metadata of the research papers to ensure the papers reported on research relevant to the context of the study e.g. CSCD. The second step was to determine that research within papers found aligned with the aim of the research supporting knowledge building on evaluation and selection of suitable technology for CSCD.

Towards the first step, the 477 papers were considered. Covidence was once again used to analyse the data and record if the paper was to be included or excluded. Keywords, titles, and abstracts were used to determine if the research detailed in the papers had relevance to the context of the study in CSCD (thematic inclusion). The research fields that were determined to be relevant are included in Table 4-4. Those that were not relevant were those that detailed individual designers and not design teams, and those that were outside the research field of engineering design, e.g. global collaborative events management teams (where the teamwork is clearly not related to engineering design) or outside the field of CSCD, e.g. collocated non-technological design techniques.

A further 243 papers were removed at this stage because they did not relate to an appropriate field of study. To achieve step 2 of exclusion criteria three being ‘papers supported the evaluation and selection of suitable technology supporting CSCD’ further reading beyond the metadata was required. 234 papers were determined relevant to the next step of the study. Each of the 234 papers was read in full.

Summaries of each paper were created to capture the key contributions related to the search question. The template used to create these summaries included recording of paper title, authors, Journal/conference i.e. the source, year, topic, field, keywords, a brief description, summary of the literature section, summary of the research/study, summary of the conclusion i.e. outcomes. A sample of the summary is illustrated in Figure 4-3.

Table 4-4: Research field of initial results determined through meta data analysis

Research field	Number of papers
Aerospace	3
Architecture	19
Civil Engineering	2
Engineering Cognition	1
Collaborative Learning	9
Collaborative Meetings	1
Communication Research	1
Computing	2
Education	5
Electronics Engineering	1
Engineering Design	49
Furniture Engineering Design	2
Interior Engineering Design	1
Participatory Design	1
Product Design Engineering	72
Product Development	3
Project Management	1
Pure Design	2
Software Design	10
Software Development	31
Software Engineering	16
Space Engineering Design	1
Systems Engineering	1
Total	234

Paper Title	Understanding the Influence of User Participation and Involvement on System Success - a Systematic Mapping Study
Author's	Abelein, Ulrike. Paech, Barbara
Journal/conf	Empirical Software Engineering
Year	2013
Topic	Case Studies and Reviews, systematic Mapping, User participation and involvement (UPI)
Field	Software
Keywords	User-centred design. Trust.
Brief Description	User Participation and Involvement can be beneficial to the final product and customer satisfaction. If this is true what are the characteristics?
Summary of the literature review	
UPI—Key to a systems success. involving users is critical to develop good solutions (Hope and Amdahl 2011). improved quality due to more precise requirements and the prevention of unneeded, expensive features. Furthermore, users who feel involved in a software system will have a positive attitude and perceive it as more useful, thus they are more satisfied with the system (McGill and Klobas 2008). it is essential to summarise and analyse existing methods of UPI in order to understand the existing method landscape and its limitations	
Summary of the research/study	
A Systematic Mapping Study—289 papers. 2nd author validated the papers. (58 papers were statistically analysed). Approaches to User Involvement and Participation. participatory design, user- centred design, ethnography, and contextual design. The major difference between those approaches is how active the users are and whether they actually participate in decision-making (Kujala 2008). User-centred design comes from the research area of human-computer-interface (HCI). It puts the user, instead of technical needs, into the centre of design. Therefore, the designers focus on the users' context (Kujala 2003). Does increased UPI lead to increased system success? What are the characteristics of methods which aim to increase UPI in software development? Current methods for increasing UPI. Which activities are involved with this? Validation of these methods?	
Summary of the conclusions	
CATAGORIES AND SUBCATAGORIES **Development Process** User participation. User-developer Communication. Model of Development **Human Aspects** User Involvement. User Motivation. User Intention to use. User attitudes towards the system. User's ability in IT projects. User beliefs about developers. Developers attitudes towards user. Disagreement/conflict. **System Attributed** Complexity. Uncertainty **Organisational Factors** Top Management Support. Organisational or management structure. Availability of resources. **System Success** User Satisfaction. Ease of use. System Use. System Quality. Data Quality. Project in Time and Budget. **Does increased UPI lead to increased system success?** **10 % of the correlations are negative (14 of 146 links).**	

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Figure 4-3: Example paper summary

In producing the paper summaries, the researcher aimed to better understand the field by conducting a thematic analysis. Initial themes were created to support the building of knowledge within the field. 71 themes were created. These are:

- 3D CAD
- Ambiguity
- Book chapter/summary
- Capturing knowledge
- Cloud computing
- Cognition
- Collaboration management
- Collaborative design network
- Common language
- Communication
- Computer-mediated design methodology
- Computer-supported collaborative learning
- Conflict management
- Contextualisation
- Crowdsourcing
- Customer evaluation
- Customer testing
- Data handling
- Decision making
- Design game
- Design process
- Design rationale
- Education
- Encouraging collaboration
- Engineering systems
- Establishing a collaborative environment
- Facilitating collaboration
- Gestures
- Group decision making
- Groupware
- Ideation
- Interactive tabletop
- Internet of things

- Knowledge acquisition
- Knowledge reuse
- Learning through games
- Mobile collaborative design
- Model
- Multiple
- Negotiation
- Network analysis
- Participatory design
- Patterns
- Process analysis tool
- Project based learning
- Risk management software
- Shared understanding
- Shared wall displays
- Shared whiteboard
- Socio-technical
- Software development
- Systematic mapping
- Team analysis tool
- Team building
- Team development
- Team empowerment
- Toolkit
- Traceability
- Trust
- Twitter
- Video conference
- Virtual customer testing
- Virtual reality
- Virtual world
- Wiki
- Workspace

The most popular themes were: models of collaboration (19 papers), 3D CAD software development (16 papers), collaborative software development 16 papers), use of or development of a shared whiteboard (15 papers), and interactive tabletops (13 papers).

A literature synthesis matrix (Appendix 3) was created to understand the research completed within the field. A categorisation of the 234 papers was performed into five categories that emerged from reading and coding the papers. The five categories were technology tools and methods, case studies and reviews, knowledge management, human factors and user participation.

Technology, tools, and methods relate to developing or using different technologies, tools, or methods that support CSCD teamwork. 130 papers documented this research which was the most popular area. This category also featured reflection on the use of technologies, tools and methods from a human-to-computer interest. Knowledge management (31 papers) and human factors (18 papers) focused more on the theories of supporting CSCD teamwork through knowledge management procedures or the issues that arise in human-to-human collaboration practice. Finally, user participation (24 papers) and case studies and reviews (31 papers) focused on documenting a study and how it was conducted.

Upon reflection of the 234 papers, there were four motivations within the research. These were benefits, barriers, requirements or opportunities. 14% of papers highlighted the benefits of CSCD, 29% highlighted barriers to conducting CSCD, 53% discussed requirements of CSCD, and 4% discussed opportunities for CSCD. The results of this coding stage are displayed in Figure 4-4, which demonstrates that the majority of research outcomes within the field are focused on establishing requirements for CSCD.

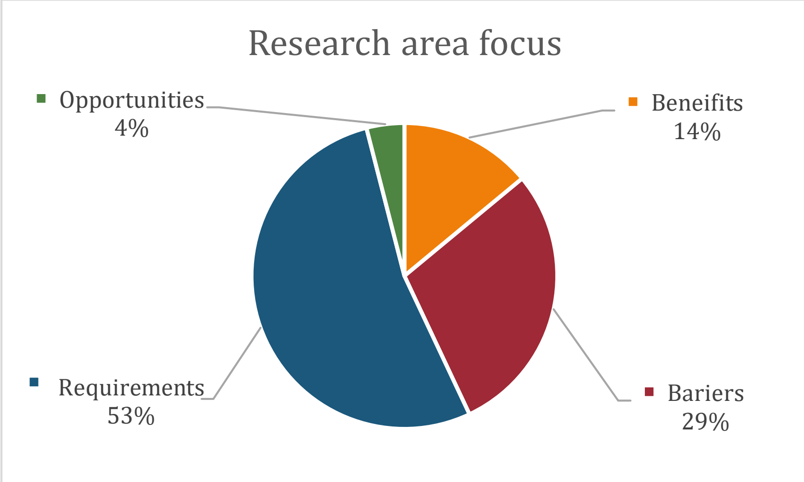


Figure 4-4: Outcomes of the paper categorised

Not all papers contributed towards the purpose of the literature review in supporting CSCD - for example some papers were related to the development of software and requirements of software development. Other papers related to experiences of team members without explicit outcomes for change or recommendations for best practice. Also, some papers reported issues at a high level, focusing on developing cognitive models to understand collaboration, and without real-world application. However, 27 papers were identified that stated an explicit list of requirements of CSCD,

These 27 papers contained 220 requirements for CSCD. The complete list of requirements mapped to their sources is included as Appendix 4 listed by paper and author alphabetically.

Antunes et al. (2011) presented the findings from a research project on the collaborative design of a map. Popular technology at the time was used to support the collaboration in what the authors refer to as a Group Support System (GSS), including technologies such as; Wikipedia, Facebook, LinkedIn, Doodle, Dropbox, Twitter, Zoho, Google Docs, and Google Maps. 48 participants took part in what could be classed as a large group; however the contribution of the team members was equally high, which is not similar to open innovation groups. The group size contributed to barriers in the process being the large volume of data to handle, however, the high activity levels stimulated participation through positive reinforcements, constant feedback and peer pressure.

With a focus on group size, influence, awareness, usability and participation, the research found a high number of participants (98%) who perceived group size impacted the task and 100% who could perceive comments of other team members well. However, 73% of the participants felt they were subject to information overload principally due to the size of the group. Antunes et al. (2011) concluded by stating that although there are great opportunities for large group collaboration, smaller groups are adequate for current GSS tools.

The requirements extracted from Antunes et al. (2011) were: encourage synergy of team; be provided with positive reinforcement to encourage information flow; support contextualisation over distance; support contextualisation with relationships; share a global view in the aid of a shared understanding; share a global view to reduce information overload; reduce difficulties in coordination due to technical difficulties.

Benolken et al. (2010) described the development of a distributed design work-space tool by identifying functionality that supports collaboration. Features of the developed software include the organisation of meetings to coordinate and schedule meeting times, and information required for the meeting, including documents, data, information on stakeholders and applications that support collaboration, including a whiteboard. The developed software also includes shared visualisations of 3D assemblies and the ability to point and annotate onto the 3D view. The software itself relied on existing conferencing and chat software packaged as a toolkit.

The requirements extracted from Benolken et al. (2010) were: allow for shared visualisation of work; support the organisation of meetings; support audio and video conferencing; allow for messenger style communication.

Bittner & Leimeister (2013) aimed to apply van den Bossche’s causal model to improve heterogeneous teamwork. This included the identification of the influence that a shared understanding has on collaborative design teamwork. The research is theory-based and within this paper, the authors were not able to prove that the model would have the desired effect of increasing team performance. Bittner and Leimeister split the collaborative design process into seven design activities with the aim to improve performance by artificially changing the collaborative design process.

Bittner and Leimeister also reflected that technology at the time was not optimal to support the design process, in particular, the groupware named Think Tank 3.0 hindered the articulation of descriptions of problems and solutions. This is not uncommon when teams are more familiar with verbally collocated communication and switch to digital platforms.

The requirements extracted from Bittner & Leimeister (2013) were: convey individual personality; encourage team familiarity; organisational culture; authority; have an understanding for the impact of physical proximity; be incentivised in their work; be in good morale; performance (quantity of output); assist in the reduction of iterative loops; assist in the reduction of rework; support group member satisfaction; have a diverse range of skills; have individual skills; coordination; support innovation; performance (quality of output); support communication.

Borsato et al. (2015) present a literature review of collaborative engineering, including the factors that influence projects, the software used and the future of collaborative engineering. The authors provided conclusions from their inquiry into the literature, including underestimating the cost, time, overheads, and risks in collaborative engineering projects, which is a barrier to dynamic teams. There was also a general sense that the authors believed that the research was incomplete. They stated: "Collaborative design systems still need to integrate results from human sciences in order to address the cultural differences, not only between designers and product users, but also among other stakeholders", and elaborated by stating that this research is required for computer-based systems to be developed to better support designers, if not mimic their actions. This identification supports the aim of this research in developing an evaluation and selection method.

The requirements extracted from Borsato et al. (2015) were: allow for serendipitous communication; encourage networking; support a pervasive experience; make team members aware of work; cooperate with each other; coordination; support collaboration.

Cho & Cho (2014) conducted a comparison study on the effects of online and offline collaborative teamwork. 29 students took part in projects in both scenarios and responded to a survey on their experiences and perceptions of each. The study found that students preferred offline collaboration, and that online collaboration was less effective, with students typically producing fewer high-quality concepts. However, online collaboration supported time management and was perceived as being more efficient. The outcomes of the class did not indicate a statistical difference between the two modes of collaboration.

There were technical issues regarding the online tools that may have influenced the perception of the tool, including difficulty uploading files, difficulty in viewing files and difficulty sharing feedback. The blackboard LMS tool used was not suitable for the task. In general, the students found the technology used, did not foster creativity or engagement that is clearly of fundamental importance for design.

The requirements extracted from Cho & Cho (2014) were: enhance interpersonal skills; accept a sense of lack of control; avoid miscommunication; ensure equal participation by all; allow for greater opportunities to express opinions; learning negotiation skills; more thorough outputs; ensure efficiency in communication; productivity; enhance communication skills; ensure more capable employee skills; more creative outputs.

French et al. (2016) aimed to determine what could be learned from the game Minecraft to make CAD collaboration more engaging. The features that influenced the perception of Minecraft as an excellent collaborative tool were the ease of communication methods and learning from other participant's building to improve one's own skills. Builders preferred to work together than alone with leaders working collaboratively 70% of their time, and non-leaders 50% of their time. However, it was observed that with greater collaboration also came greater conflict and disagreements.

The requirements extracted from French et al. (2016) were: be encouraged to have a long-sustained interest in the project; be made awareness of other team member's actions; allow for a constant connection; more opportunities for peer learning and training; greater retention of learning; encourage greater team trust when required; allow for improved decision making; greater likelihood of catching mistakes; faster design through collaboration; reduced rework time; reduce complexities whilst sharing data.

Fruchter et al. (2010) investigated the human factors associated with global teamwork, particularly focussing on building a common ground of understanding between team members. They suggested that the communications between team members was commonly recorded in a textual form, however, the thought process towards decisions was much more difficult to capture. They conducted an investigation of the ways team members might record decisions, and a schema for activities in teams was suggested, including clarifications, explanations, explorations, problem-solving, closed questions, feedback, presentation, negotiation, resolutions and other (which appears to be coordination of the team). These appear to be a representative of the communication actions that a team might have.

Fruchter et al. suggested that the re-representation of concepts, which means to represent ideas using several multimedia approaches multiple times in the development process, was able to accelerate common ground building between team members. This can also be applied to communication through different means, including speech, diagram, annotation and gestures.

The requirements extracted from Fruchter et al. (2010) were: allow for feedback on ideas; support resolution of discussions; present information in an easy to understand way; allow for clarification of a statement; allow for explanation of a statement; allow for negotiation; allow for the asking of closed questions; assist in negating scheduling problems; support exploration; support problem solving; reduce technical problems.

Gericke et al. (2010) documented the development of a trans-synchronous wall that supported the handover of process between design teams. Trans-synchronous refers to the use of the wall either synchronously or asynchronously. The development focussed on user interaction, communication protocol, performance, a history browser, and asynchronous interactions. Further investigation was required to integrate audio and video into the wall, and to better understand the requirements of the history browser for the user. The functionality of the wall to look back at the history of communications and design activities was appropriate for the teams working habits. However, Gericke reflected that it is difficult to determine what functionalities of the wall are required at what time, and for the team to find that information in the moment.

The requirements extracted from Gericke et al. (2010) were: allow for the capture of meeting information; support the reuse of data; integrate with data storage systems.

Gopsill (2014) utilised published literature in engineering design, professional communication, knowledge and information management, computer-supported collaborative work and project management to build a framework to support engineering design communication based upon learning from social media. Gopsill identified that modern social media technology has the functionality to support engineering design teams such as tagging, linking, hindsight and awareness. The framework supported the development of a tool enabling engineering design team communication, enabling team members to detail the requirement of engineering design communication, the purpose of the communication, the response type required and the artefact type i.e. a sketch, prototype, FEA data or other.

The requirements extracted from Gopsill et al. (2014) were: allow response with high quality representation examples; provide an electronic or physical reference for communication; allow team members to add comment to past communication; allow team members to define a response to communication; seek input from parties outside the design team; allow the ability to define the purpose of a conversation; allow for the capture of high quality representation of artefacts; allow for the recording of modifications to the artefact; allow for text based description; record and capture the focus of the conversation; limit the size of the response; include the ability to conclude a conversation thread; allow for the organisation of communication by grouping; allow for the response to be coordinated to the correct purpose; allow for the categorisation of communication; allow for referencing previous communication; allow for organisation of communications; allow for easy linking between communications; allow for pushing of information; support the answering of multiple threads through a single response; support multi-threading conversations.

Hansen & Dalsgaard (2012) documented a participatory design workshop in which primarily physical artefacts were used to enable all participants to contribute. A digital screen, 3D videos and maps were used to support understanding of the design project. Hansen & Dalsgaard reflect that the use of materials supported the discovery of new problems and highlights the differences between digital artefacts and physical artefacts in the design process.

The requirements extracted from Hansen & Dalsgaard (2012) were: allow for the documenting of decisions; allow for the reflection on work and decisions; support an aligning effort of their team members; support the rapid transformation of ideas; support the proposition of design change; support design change.

Herrmann et al. (2013) documented the outcome of three studies related to the use of technology to facilitate and share ideas between collocated team members. The collaboration was based on brainstorming within a shared space using mobile devices and custom software. Recommendations for the development of the software were made, including the ability to easily switch between topics and other administrative functionality.

The requirements extracted from Herrmann et al. (2013) were: allow for the addition of artefacts to text-based ideation; allow access to edit documents; encourage team members through gamification; be made aware and notified; support rework after the fact; support easy switching between ideation topics; support synchronous working with live documents.

Hirlehei & Hunger (2011) documented the decisions made in designing and developing a groupware tool for synchronous collaboration. The factors that influenced the development were identified as: establishing a common ground; establishing a common context; coupling of work; i.e. how the type of work relates to the communication;

collaboration readiness; technology readiness; team experiences; culture awareness; and, differences in time zones. From establishing these factors and considerations for supporting distributed collaboration, a tailorable groupware application was created.

The requirements extracted from Hirlehei & Hunger (2011) were: difference in time zone; have a cultural awareness for distributed team members; discuss problems with a common context; communicate on a common ground; collaboration readiness; technology readiness; coupling of work; contribute to the team experience.

Horváth (2012) summarised the development of research in the field of Computer-Supported Cooperative Work in Design over the years. CSCWD has many similarities to CSCD. The focus of this research was on communication and the purposes of group communications when collaborating. Horváth claims that the content of a communication affects not only people's understanding of that communication but also any actions as a result. It was concluded that: "a broad research and development front is needed in the field of virtual collaborative tools and systems."

The requirements extracted from Horváth (2012) were: employ smart support of process control systems; allow for the mining of information; support knowledge elicitation methods; support intelligent asset management; integrate 3rd party program support e.g. CAD; have an adaptive system interface; allow for model and document sharing; support multi-channel working; support co-creation in smart ways; communication channels; support virtual presence in smart ways.

Iacob (2011) conducted research to determine patterns in human behaviour during synchronous collaborative drawing. The results were a mixture of requirements and features (AKA functionality of technology) to support collaborative drawing.

Features identified included: tagging, ranking, the ability to text chat, notification, identification of team members, annotating and commenting, history tracking, ability to annotate work, changing documents, preventing changes, custom views of the UI for different stakeholders and automatic shared summaries. This functionality of technology support the team in their CSCD projects.

The requirements extracted from Iacob (2011) were: display summaries of work completed; have access to view and edit files freely; have freedom to collaborate with whoever is required; give an awareness of other team members work; ranking functionality; allow for annotations on existing artefacts; consistent interface; support device flexibility; allow for everyone to take part at once; support communication through an integrated chat client; support tracking work / versioning of documents; provide a private space to work; employ a mechanism to handle the resources; integrated tagging functionality.

Jinghua et al. (2014) developed rules for collaborative design coordination to support the development of scheduling software. The basis for the rules is the human factors that influence distributed teams work. Rules included: Identifying who has the largest workload, eliminating difficult tasks, and identifying the best team member for a task, transferring tasks between team members.

Jinghua et al. found that the rules implemented can influence the outcomes, and so, for any team, it is possible to use these rules to develop a best approach to use.

The requirements extracted from Jinghua et al. (2014) were: ensure work is completed by the most compliment member; support the even distribution of work.

Liu et al. (2014) discussed the decision-making process associated with the development of a collaborative design platform. The platform allowed a manager to coordinate teamwork and receive updates on work completed. The approach to the development of the platform was to utilise knowledge of Product Service Systems (PSS), with consideration for the user's experience. Due to the use of this approach, the recommendations created were distinctive to other recommendations of its type, including; the need to match the context of the use to the design task, and the need for the system to support iterative design changes and evaluation of design.

The requirements extracted from Liu et al. (2014) were: articulate their completed work; give an awareness of team members activities; select appropriate technology or tools.

Luck (2013) investigated misunderstandings caused by ambiguity and uncertainty during team meetings. A text analysis process was used to identify areas of ambiguity and uncertainty. The factors that were identified as contributing towards these misunderstandings related to: over planning of meetings; lack of clarification; interdisciplinary confusion; and, suggesting solutions without much thought. Luck stated that these findings were not caused by poor design management or performance of the team members, but there was some evidence that problems were overlooked in preparation or during the meeting discussions.

The requirements extracted from Luck (2013) were: avoid ambiguous misunderstandings; avoid uncertain misunderstandings.

Pavkovic et al. (2013) aimed to support design communication through the provision of traceability of engineering information. The proposed methodology was demonstrated to support a shared understanding between team members through semantic searching within specific contexts and additional metadata about relationships between information nodes. Using this approach Pavkovic et al. addressed the issue of reusing knowledge and traceability of this knowledge. They concluded that reflection on manufacturing problems and malfunctions using previous information can be beneficial in educating novice designers.

The requirements extracted from Pavkovic et al. (2013) were: allow access to information; delegate clear roles and responsibilities; anticipate the needs of other team members; encourage regular project reviews; encourage mutual trust; give a visual overview of tasks; support the autonomy of tasks; support collaboration; reduce technical conflict.

Rapanta et al. (2013) reported on the problems in online learning for design students working in teams. They identify three challenges of design education teamwork:, discussions of problems and solutions overlapping highlighting the importance of exploration in the design process; small discussion and negotiation cycles to increase frequency of design decisions and momentum in project work; and, the identification of the nature of design as simply problem-solving which is an inaccurate characterisation. Problem solving is important and may be a significant part of designing, problem solving may include creative approaches and evaluation of ideas, however, there design is also about the management of the process, the resources, the communication, the environment and so many more aspects.

The requirements extracted from Rapanta et al. (2013) were: encourage knowledge sharing; support human to human connections; implement consistent corporate policies; support small team negotiation cycles; have appropriate training with groupware systems; overcome cultural barriers; overcome language barriers; encourage employees who are unwilling to cooperate; support co-construction activities; encourage employee trust; problems and solutions develop at the same rate and time; reduce file compatibility issues between groupware systems; reduce software incompatibility; be informed of the benefits of groupware.

Shen et al. (2015) presented a review of CSCD research. There is a focus on three pillars of CSCD: communication, coordination and cooperation, and the roles these play in supporting collaboration. Although the research entirely used secondary data sources, it demonstrated an important role in summarising some of the CSCD success factors, including the need for strategies. These success factors included having an efficient communication strategy, and integration strategy linking design activities with technology, and an interoperability strategy that influences manufacturing applications.

The requirements extracted from Shen et al. (2015) were: allow for monitoring of feedback from manufacturing and assembly; use standardised procedures; allow for direct supervision of team members work; encourage mediated coordination; support efficient decision making; predictive behaviour; new strategies for efficient communication (ideas and comments); allow for ease of sharing; allow for the integration of software.

van Dijk & van der Lugt (2013) discuss the impact of having a shared understanding on the design process. Van Dijk & van der Lugt suggested the following definition: "shared understanding is sustained in ongoing reflective conversations between people and artefacts during real-time group activities. Shared understandings are fluid, dynamic entities. Shared understanding is strongly socially scaffolded. Embodied activities in the space directly facilitate participants' social positioning, which in turn directly influences the way the session evolves." This definition was important as it reflects a change in thinking at the time by researchers. This change was a decrease in the importance of knowledge representation and an increase in the importance of supporting knowledge exchange activities. It was more important to facilitate the knowledge exchange than the structure of the knowledge.

The requirements extracted from van Dijk & van der Lugt (2013) were: encourage engagement; support single tasking.

Vyas et al. (2010) and Vyas, Nijholt & van der Veer (2010) documented research relating to the use of Twitter within the design process that enabled the mobile tagging of communications between team members. This technology was demonstrate to support feedback on developed ideas from stakeholders. There was a high level of coincidence between stakeholders when using Twitter in this way.

The requirements extracted from Vyas, Nijholt, Heylen, et al. (2010) were: incorporate artefacts into the online design space; adapt to the social needs of the designer; artefact-mediated interaction; encourage social flexibility; allow for artefact-mediated interaction; explore creative solutions; utilize spatial resources.

The requirements extracted from Vyas, Nijholt & van der Veer (2010) were: cooperate with each other; support creativity; support exploration; support multi-channel communication.

Vyas et al. (2012) investigated the importance of the designer's space meaning the technological in supporting collaboration practice. The outcome was the identification of four areas where collaborative design technologies should be developed to support designers from two case study investigations. These were the requirements for artefact-mediated interaction; utilising physical spatial resources; supporting creative explorations and social flexibility.

The requirements extracted from Vyas et al. (2012)were: support innovative thinking; integrate technology into the offline space.

Wangsa et al. (2011) argues in support of a CSCW model to support areas of technology use. These areas are user requirements: to effectively support the mechanisms of inter-organisation and intra-organisation collaborative work, to handle conflict aspects multi-perspective user needs, how to conceptualise the constantly changing problems and the need to understand the context use of the collaborative working environment. Wangsa et al. provided no indication as to how these complex issues might be addressed.

The requirements extracted from Wangsa et al. (2011) were: support human computer interactions; overcome boundaries of access; historical development; have an awareness for community differences; have an awareness for cultural differences; have an awareness for environmental differences; communicate context; minimise conflict; be objective oriented; ensure a hieratical structure of activity.

Xie et al. (2010) presented a modular model for a CSCD system that could adapt to meet the requirements of different types of teams. Using a survey, communication problems were collected and a case study was conducted to better understand the communication issues. A prototype system is presented that focuses on the handling of design objects to support the design process. The author discusses how partnerships can eliminate communication barriers and can contribute positively to social collaboration. Communications should be put in place to reduce any negatives and co-location can support interaction levels.

The requirements extracted from Xie et al. (2010) were: reduce interpersonal barriers; effectiveness of procedure; support the understanding of information; avoid poor communication; accuracy of information; conflicting information; not distort the meaning of the message; assist in overcoming logistic barriers; minimise information overload; ensure completeness of communication; avoid a lack of coordination; act as a gatekeeper to communication channel; act in a timely way; assist in reducing information overload.

Zheng & Feng (2012) aimed to alleviate the issues of CSCW in collaborative product design using the Internet of Things (IoT). The authors focussed on creating a framework for the whole lifecycle development and management from the perspective of the supply chain. The model contains four areas: an application interface, cloud platform, data transfer and fundamental hardware. Cloud storage deals with cloud computing applications and the storage of data in several databases i.e. equipment, parts, designers and components to support design through digital tools. Hardware relates to RFID, image sensors and smart terminals which supports a pervasive collaborative product design platform. This framework is different from others is that the implementation of IoT helps coordinate work and the supervision of work conducted, connecting the entire process.

The requirements extracted from Zheng & Feng (2012) were: allow for reflection on customer feedback; allow easy access to product data; support the synchronisation of data.

4.1.7 Critical analysis of the literature

The requirements identified in each of the papers were themed to identify common ideas, agreements and disagreements in the literature.

Technologies that support CSCD can enable communication channels to provide artefact mediated communication, feedback mechanisms and social communication. These communication approaches support the relationships that have developed between team members. Artefact-mediated communication typically uses high-quality digital representations of physical work and ideas such as images. They can offer design teams the ability to elaborate on text-based communication for enhanced communication and understanding (Vyas, Nijholt & van der Veer 2010; Vyas et al. 2012; Herrmann et al. 2013; Gopsill et al. 2013). Feedback from stakeholders is crucial to the design process, including the ability to view and respond to past communication supporting reflection on work (Fruchter et al. 2010; Zheng & Feng 2012; Gopsill et al. 2013; Shen et al. 2015). Social communication encourages team synergy, knowledge sharing and serendipitous communication by supporting networking within and outside the core design team and enabling team members to build their interpersonal and negotiation skills (Vyas, Nijholt & van der Veer 2010; Xie et al. 2010; Antunes et al. 2011; Iacob 2011; Wangsa et al.

2011; Vyas et al. 2012; Bittner & Leimeister 2013; Rapanta et al. 2013; Cho & Cho 2014; Borsato et al. 2015).

Technologies that support CSCD take many different forms of the collaborative environment, including collocated, distributed, real-world and digital environments to support access and integration into the company's design process. Technologies have the potential to overcome access boundaries to view and edit files seamlessly (Wangsa et al. 2011; Iacob 2011; Herrmann et al. 2013; Pavkovic et al. 2013). Integrating collaborative technologies with standardised procedures and policies enable teams to assume clear roles and responsibilities, reduce the sense of lack of control and optimise team negotiation cycles (Xie et al. 2010; Iacob 2011; Wangsa et al. 2011; Bittner & Leimeister 2013; Gopsill et al. 2013; Pavkovic et al. 2013; Rapanta et al. 2013; Cho & Cho 2014; Shen et al. 2015).

Technologies that support CSCD enable consideration and support for team membership characteristics and inter-team relationships. The barriers of physical proximity, cultural understanding, different languages, and different time zones can be supported with collaborative technologies and enable greater awareness of community and environmental issues (Hirlehei & Hunger 2011; Wangsa et al. 2011; Bittner & Leimeister 2013; Rapanta et al. 2013). Motivation through social incentivisation, positive reinforcement, gamification and encouraging good morale can be supported by collaborative technologies to ensure long sustained interest in the project (Fruchter et al. 2010; Antunes et al. 2011; Bittner & Leimeister 2013; Herrmann et al. 2013; Rapanta et al. 2013; van Dijk & van der Lugt 2013; French et al. 2016). Collaborative technologies can enable shared understanding through defining and framing conversations in a common context through shared pervasive environments, that make it easy to understand information, clarify meaning and reduce miscommunications (Fruchter et al. 2010; Xie et al. 2010; Antunes et al. 2011; Hirlehei & Hunger 2011; Wangsa et al. 2011; Gopsill et al. 2013; Luck 2013; Cho & Cho 2014; Liu et al. 2014; Borsato et al. 2015). Collaborative technologies can enable cooperation through enabling a constant connection and increased awareness to encourage equal participation, anticipation of project needs, supporting design activities and opportunities for peer learning (Benolken et al. 2010; Vyas, Nijholt & van der Veer 2010; Xie et al. 2010; Iacob 2011; Herrmann et al. 2013; Pavkovic et al. 2013; Rapanta et al. 2013; Cho & Cho 2014; Liu et al. 2014; Borsato et al. 2015; Shen et al. 2015; French et al. 2016). Trust can be encouraged by collaborative technologies to support conflict resolution through increased accuracy and clarity of communication between team members (Xie et al. 2010; Wangsa et al. 2011; Pavkovic et al. 2013; Rapanta et al. 2013; French et al. 2016).

Technologies that support CSCD must be compatible with the existing process and structure restrictions of a team and/or organisation. Including mechanisms for decision making support, knowledge capture and objective focused communication. Decision making can be supported through increased opportunities to express opinions online, enabling team members to develop negotiation skills and concept ranking functionality (Fruchter et al. 2010; Iacob 2011; Cho & Cho 2014; Shen et al. 2015; French et al. 2016). Knowledge capture is supported by recording physical information, decisions and artefacts to document the decision-making process (Fruchter et al. 2010; Iacob 2011; Hansen & Dalsgaard 2012; Vyas et al. 2012; Gopsill et al. 2013). Collaborative technologies can enable productivity through fast objective focused communication, organisation of work, reflection on completed work and a higher quantity of output to promote collaboration readiness and reduced rework time (Gericke et al. 2010; Xie et al. 2010; Hirlehei & Hunger 2011; Wangsa et al. 2011; Hansen & Dalsgaard 2012; Bittner & Leimeister 2013; Gopsill et al. 2013; Herrmann et al. 2013; van Dijk & van der Lugt 2013; Cho & Cho 2014; Jinghua et al. 2014; Shen et al. 2015; French et al. 2016).

Technologies that support CSCD, can support teamwork through increased availability of resources: greater accessibility, coordination, innovative thinking, and knowledge management opportunities. Collaborative technologies can support competency through increased accessibility of team skills and experience, reduction of unnecessary information, and completeness of messages (Xie et al. 2010; Hirlehei & Hunger 2011; Bittner & Leimeister 2013; Gopsill et al. 2013; Cho & Cho 2014). Coordination can be supported by a shared space for the organisation of work and ease of communication, simple mechanisms for scheduling meetings and supporting the even distribution of work (Benolken et al. 2010; Fruchter et al. 2010; Xie et al. 2010; Iacob 2011; Wangsa et al. 2011; Hansen & Dalsgaard 2012; Horváth 2012; Bittner & Leimeister 2013; Gopsill et al. 2013; Pavkovic et al. 2013; Rapanta et al. 2013; Jinghua et al. 2014; Borsato et al. 2015). Innovative thinking is supported by enabling agile systems to support exploration, creativity and quality of outputs. Knowledge management is enabled through the organisation of information and communication, the ability to search and retrieve knowledge easily, and autonomy in the distribution of knowledge (Xie et al. 2010; Antunes et al. 2011; Iacob 2011; Horváth 2012; Gopsill et al. 2013; Pavkovic et al. 2013; Shen et al. 2015). Complexity in sharing data can be reduced through integration with data storage systems, reduced file compatibility issues and synchronous live document working with automated tracking and versioning to enable co-creation of documents, and communication can be enhanced through synchronous multi-threaded and multi-channel software for prompt discussion in a way which supports the context of the message (Benolken et al. 2010; Fruchter et al. 2010; Gericke et al. 2010; Vyas, Nijholt & van der Veer 2010; Vyas, Nijholt, Heylen, et al. 2010; Antunes et al. 2011; Iacob 2011; Hansen & Dalsgaard 2012; Horváth 2012; Vyas et al. 2012; Zheng & Feng 2012; Bittner & Leimeister 2013; Gopsill et al. 2013; Herrmann et al. 2013; Pavkovic et al. 2013; Rapanta et al. 2013; Liu et al. 2014; Borsato et al. 2015; Shen et al. 2015; French et al. 2016).

From analysis of this CSCD requirements-oriented literature, three themes were emerging on the use of technologies for CSCD to support the design process. Three themes were created through a thematic categorisation of the support of the exchange and development of ideas, artefacts and documents; supporting reasoning and discussion of design decisions; and, supporting collaborative design activities. Each of these themes of papers is discussed as follows.

Support of the exchange and development of ideas

Gopsill et al. (2013) reported on the importance of the ability to capture design work using CSCD technologies by collaborative engineering design teams. The capture must be of the "right dimensions", meaning the appropriate work for the development of concepts. This requirement is linked with searchability, retrieval of design work and awareness of the work uploaded by design team members to CSCD technologies. These requirements are integral to CSCW research, to ensure all team members have access to the information they need, when they need it, and in the correct format. When engineering design teams engage in ideation tasks, it was suggested that they need the ability to easily switch between ideas (Herrmann et al. 2013). This relates to the functionality of CSCD technologies used by engineering design teams and the awareness of teams regarding the current topic of discussion. Herrmann et al. (2013), also discussed the role that individual and group thought has in the ideation process, and how it should be easy for team members to switch between these two states frequently.

On the topic of ideation, the artefacts that have been captured on CSCD technologies must in some way be utilised to support ideation and drive the project progress (Gopsill et al. 2013). An artefact can be an image, video, or descriptive text, for example, that represents an idea, design change, or design decision. It can act as a focal point for aspects of the design allowing team members to discuss specific features of a concept aided by a visual representation. CSCD technologies can support ideation through iterative development using multi-threaded conversations and drive the project through greater awareness functionality. In addition, CSCD technologies must allow for artefacts to be modifiable (Gopsill et al. 2013) and allow for mark up using annotations (Iacob 2011) both of which can be achieved with CSCD functionality of multi-threaded communication and tagging. Although the artefact acts as a focal point, as stated before, it can be altered, changed and updated iteratively to document the development.

Fruchter et al. (2010) suggested that problem-solving activities could be improved with the exchange and development of ideas using CSCD technologies as it builds a common ground for team members to share. Exploration of a problem as a group introduces common discussion and drives "convergent design thinking" (Fruchter et al. 2010).

Hansen & Dalsgaard (2012), discussed the role of technology to support the transformation of ideas into concepts. This involves the generation of ideas and the use of design material to support this. In a typical design studio environment, work is completed synchronously with all available team members. CSCD technologies can connect team members asynchronously and provide the capability to allow design work to be conducted on the team member's terms. Ideas can be transformed at any time and with greater opportunities for input from all stakeholders.

When design team members discuss a problem, it is useful for that conversation to be marked as complete once decisions have been made. This ensures that team members are aware of how the project intends to progress. A completed conversation can act as an agreement of the work that needs to take place and an indication that no further action is required (Xie et al. 2010).

Supporting reasoning and discussion of design decisions

Team members require a forum to allow them to share their opinions (Cho & Cho 2014). CSCD technologies can ensure team members are able to share their opinions in an easy way and inclusive of all team members' needs and confidence levels, without giving precedence to any team member. In addition, all team members must have the ability to use the CSCD technologies to suggest design changes (Hansen & Dalsgaard 2012). During the design process, problems and solutions can come from any team member focusing on any aspect of the design, so it is important to give all team members the same importance. This includes the ability of the technology to support negotiation (Cho & Cho 2014; Fruchter et al. 2010) between team members.

Engineering design teams require the ability to rate and rank concepts (Iacob 2011). CSCD technologies can support this by ensuring it is easy for team members to engage in design meetings and activities, including *liking* images and providing inbuilt and dynamic voting mechanics.

In order to encourage discussion, Fruchter et al. (2010) suggested that it is important for engineering design teams to be able to make frequent design decisions. This practice helps to build a common ground between team members who are aware of the current work and promotes “accelerating the execution of action requests” (Fruchter et al. 2010). In addition, it is important for the design decision-making process to be well documented throughout (Hansen & Dalsgaard 2012) to ensure teams have access to all the information they might need and are aware of the progress of the project. Once decisions are made, it is essential that the technology supports the ability of the team members to implement the associated course of action (Hansen & Dalsgaard 2012). Teams need to have a system that can rapidly adapt and change, depending on the decision-making needs of the project – the environment they use has a great impact on this.

Fruchter et al. (2010), suggested that the ability to ask closed questions is essential in design teams. Both for productivity to ensure definitive answers for the decision-making process, and to progress the concept development and reduce future problems with miscommunication and misunderstanding.

When working in collaborative engineering design teams, it is important to take some time and reflect on the work. CSCD technologies have a part to play in supporting this (Hansen & Dalsgaard 2012) through awareness of conversations after the fact and notifications of updates to artefacts.

Supporting collaborative design activities

Iacob (2011) and Gopsill et al. (2013) identified the role of technology in supporting collaborative discussion between design team members and stakeholders outside the core design team. It is important to include the right people in the discussion, and CSCD technologies offer multiple communication methods and functionality to ensure this can take place. In addition, CSCD technologies provide opportunities to discuss issues informally and conveniently.

Rapanta et al. (2013) reported on the capabilities of using technology to support co-construction activities. CSCD technologies were identified as being appropriate by networking team members together and offering multiple communication methods to support discussion. This related to the group's familiarity with the technology and willingness to adopt tools to ensure best practices.

Teams have demonstrated the benefits of having communication technology integrated within design software. This has been the case, for example, in studies integrating videoconference functionality within CAD software. Iacob (2011) and Horváth (2012) suggested that this encourages more frequent discussions about specific design issues. Integrating CSCD technologies into design software has the capabilities to encourage this also.

4.1.8 Summary

220 requirements of CSCD were identified and is a contribution to knowledge (Appendix 4). Such a list in the context of CSCD to this scale has never been produced before. However, the scale of this number of requirements presented its own issue. Such a number of requirements would be difficult to process by an individual or by a team. The knowledge to fully understand each of the requirements in detail would require significant education to the person implementing the requirements to prepare for or to evaluate a CSCD project.

The researcher began to investigate ways that this list of requirements could be reduced and simplified, and/or the requirements could be handled in an automated way to support their implementation.

The systematic literature search did not produce a complete picture of the literature to support the aim. There was a need to establish other known knowledge towards achieving the aim of the research. Requirements of supporting CSCD were found, however the technologies that can be used were not clear. Some had been identified within the systematic literature search; however it was unclear if this was comprehensive as it was not the aim of this literature search. In addition, the research that discussed the use of technology to support CSCD may or may not have discussed the functionality of the technology that was used, and this may also not be comprehensive.

To overcome these issues, two additional literature searches were required to identify the technologies that support CSCD and the functionality of these technologies in more specifics.

4.2 CSCD technology review

Published literature was used as a first step to create a list of technologies used by CSCD teams. The process of creating this list of technologies is firstly described, the literature found is presented, and comments are made on the significance and appropriateness of the literature found and the technologies identified.

The outcome of this chapter is a list of technologies that have been documented within published research as being used in CSCD projects. This list contributes towards the need to establish technologies that can be used for CSCD from the literature, so that the technology selection and evaluation method can be tested and evaluated. The list of technologies created within this chapter is appropriate for CSCD studies but is not exhaustive for this purpose as the literature could not provide a complete picture, additional research and further study is required such as that detailed in Chapter 2.

4.2.1 Search procedure

The scoping search, state-of-the-art search and systematic literature search all contributed to identifying technologies for CSCD. Research reported in published literature was considered to be appropriate for this literature search if it met the criteria of reporting the use of technologies that support CSCD as an objective: '*To establish the technologies that deliver the functionalities to satisfy the defined requirements of CSCD*'.

The scoping search was used to provide a foundation of knowledge, and the state-of-the-art search updated this literature as the research progressed. When conducting the systematic literature search and reading the 234 papers in full, additional papers were found that mention specific technologies, and these were added to the literature used in this section.

To identify the technologies that support CSCD from the literature, an approach to identifying appropriate literature to review was created. First, a definition of the boundaries of the literature review was created (Figure 4-5 – Step 1) followed by the identification of literature from the scoping search, the state of the art review and the 234 papers that were read as a part of the systematic literature search (Figure 4-5 – Step 2-3). Once established, inclusion criteria supported the identification of literature that document and discuss the use of technologies in CSCD projects for engineering design teams in both industry settings and educational settings (Figure 4-5 – Step 4). 62

technologies were found. The findings were extracted from the papers and collated (Figure 4-5 – Step 5).

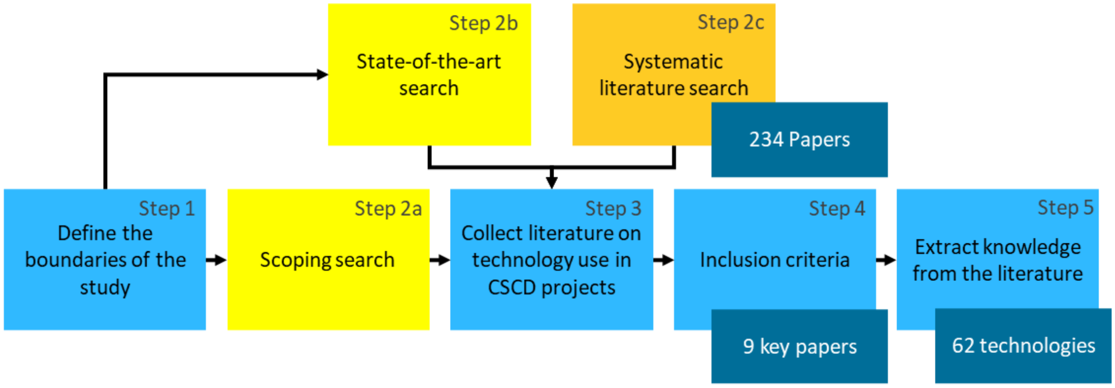


Figure 4-5: Methodology to identify the technologies to support CSCD

4.2.2 Review of the literature on technologies for CSCD

When reviewing literature relating to the use CSCD technology within collaborative engineering design projects, two themes emerged. First, there was a higher number of papers written about CSCD projects within an educational context, compared to those documenting projects that take place in industry, perhaps observations in an educational environment are more accessible to academics. And second, the focus of these CSCD projects was on the use of modern and novel technologies such as social media and social network sites used within these projects.

The motivation for the research documented in this thesis originated from an observation of students using social network sites within their global design projects to support collaborative activities. Perhaps these observations are more noticeable in education, or the use of SNS and SM are more prevalent in educational environments.

Social network sites offer functionalities that other technologies created for collaboration have not previously, and so they are typically reported with enthusiasm in the published literature due to the potential of the technologies observed. Multi-threaded conversation functionality offers the ability to comment on and reply to messages, tag team members in messages for increased awareness and like posts to show agreement. This functionality has the potential to improve teamwork and change the way we work in the future (Zhao & Rosson 2009).

Gopsill et al. (2014) presented an approach to support engineering design communication with a purpose-built social networking tool called PartBook. PartBook featured common social network functionality such as the ability to tag artefacts and team members, limiting the size of messages, tagging/categorising messages and enabling easy response to specific messages. The software was implemented within a Formula Student team at Bath university in which the software facilitated the communication of 450 messages on the development of the formula student vehicle and coordination of the team. Students also had access to Email, phone calls, SMS and face-to-face meetings in addition to PartBook. There was more communication between individual team members on PartBook compared to email, where Email facilitated communication between team leaders or gatekeepers within the teams. Individuals could contact team members who held the knowledge directly rather than information being passed through team members. The author concluded that communication using social networking websites and tools allows all team members to be aware of design changes using the notification functionality of such tools and respond to communications easily using message thread functionality.

During a study of Global Design Projects in which students from the University of Malta, City University London and the University of Strathclyde took part in the distributed design of a product, Mamo et al. (2015) used observations of the students' work to propose a framework for the technologies that can be used at different stages in the engineering design process. The technologies students choose to use to facilitate their design activities were recorded and conclusions made about their appropriateness. Mamo identified that there was a need for specific technologies for Quality Function Deployment and Product Design Specification development (Facebook and Skype), morphological chart and sketching (Facebook, Skype and cloud storage), brainstorming (Facebook and Skype), and detailed design including DFX identification, screening matrix, scoring matrix, decision matrix and CAD modelling (Facebook, Skype and Cloud storage). The technologies identified in this paper were WhatsApp, Facebook, Google Drive, Email, One Drive, Dropbox, Box and Skype; which indicated that a greater number of technologies were used by the teams that were not necessarily required.

The literature also highlighted the lack of training available to students and teachers on the use of this technology in an academic environment, and in some cases, disinterest of those who have the potential to integrate novel social networking technologies into the classroom meaning that these attempts often fail (Garcia-Perez & Ayres 2010).

Pektaş (2015) reported on the use of technologies within a virtual design studio, where student teams of about seven members were formed of students from Bilkent University, Turkey, and students from East Carolina University, USA. Technologies used for this project included the Moodle Learning Management System (LMS) with database, a forum and a wiki; videoconferencing technology (Room Voice over IP (VoIP) and Skype) and Facebook. Pektaş concluded that online technology supported students' ability to share design documents and ideas back and forth supported by the LMS and Facebook. However, the digital approach did not replicate the same type of collaboration that would be observed in a collocated design studio space, and the typical design methods taught to students were not applicable in an online setting. A blended approach is suggested for a 'best of both worlds', or it may be that online tools and design techniques need to be developed to support distributed learning.

Lippert et al. (2017) documented a student experience as part of a distributed product development project within the Integrated Product Development International Summer School. The project provided students with the experience of developing a project in person during a kick-off week, and distributed product development using technology when students return to their home countries. With this kick-off week, much of the icebreaking and familiarisation of team members took place collocated, resulting in the sense that there was greater 'faith' or trust in team members abilities. This also helped to overcome shyness or commitment to the projects later on as students have built a team bond. Students reported using Skype, Google Drive and Google Hangouts to conduct meetings, distribute tasks and report on completed work. The team did not report any synchronous distributed collaborative design activities that may have produced more creative outcomes.

Hurn (2012) reported on the impact technologies such as social software can have on Product Design Education. The research was initially proposed due to the limitation of University LMS systems and the identification that technologies could overcome challenges faced by students. The technologies that were prevalent at the time were Blogs, Youtube, Facebook, and Twitter. The researcher asked students to use a blog as part of their studies and surveyed students' opinions of blogs and other social technologies. While the data was positive in favour of a wider spread use of technology, the way questions were asked by Hurn may have introduced a bias.

Sheriff (2012) presented the results of a survey in relation to students' and academics use of technology in engineering projects. The survey included questions focussing on which technologies students use socially and for their studies. Students used Facebook, LinkedIn, Twitter, wiki's, collaborative document editors, blogs, social bookmarking websites and instant messengers for university work. The technologies enabled them to communicate with other students and to learn outside of a classroom environment. Social media websites such as Youtube were the most popular type of technology used in order to "enable users to upload media content … and share it with the internet community. In an engineering context, lecturers may wish to upload their presentations, or students could, for example, provide video updates of project work when working off-campus." This supports a more pervasive educational experience which supports peer learning and teamwork. The research highlighted that both students and academics were aware of greater acceptance of these technologies within an educational environment and that there is a gap in the understanding and use of technologies by the HE community.

SNS use encourages social communication in addition to professional (project-related) communication, which is beneficial for engineering design team work. Törlind & Larsson (2002) stated: "The highly informal, accidental, spontaneous communication that characterizes everyday work has an impact on design that sometimes is even greater than that of formal communication". This has been referred to as the *watercooler* moment in organisations that offers workers an opportunity to socialise and discuss work informally. Studies suggest social media tools are replacing physical interaction (Brzozowski 2009), and with this comes benefits for engineering design teams, particularly in distributed environments. While the informal conversation that takes place cannot be predicted, the behaviour and benefits can be encouraged by implementing social media principles (Gopsill 2014).

The majority of examples from the literature were research studies which took place in an educational context, however there were some which highlighted technologies used in industry.

Sarka et al. (2014) distributed a survey to collect data from 320 companies with respect to the social media technologies they used during daily engineering related tasks. 136 responses to the survey were received. The responses to the question on what technologies the companies used did not only contain 'social media' technologies, but also general technologies such as Google as a search engine. The technologies identified include: Blogs, Facebook, Google, Internal tools (i.e. technology solutions created by the company for specific needs), LinkedIn, Twitter, Friendfeed, Myspace, Flickr, Second Life, Skype, YouTube, Wikipedia and Xing. This may highlight that the researcher conducting this survey did not define what social media technologies are, which would lead to more general technologies. Or the distinction between a general technology and a social media technology is not important for those in industry so long as the technology supports the engineering design process. The outcomes of this study should be understood with this limitation that other non-social media technologies may not have been reported by those who use the technology but did not see the relevance to the study.

Sarka defines the purpose of using these tools that include searching for new and known information or knowledge, networking with new clients and customers and identifying possible solutions. This aligns with the requirement for CSCD of knowledge reuse, knowledge dissemination and collaborative solution identification captured in Chapter 4.1.6 by Pavkovic et al. (2013), Rapanta et al. (2013) and Iacob (2011).

Shen et al. (2015) reported on the technologies used within engineering companies across sectors of manufacturing, aviation and electronics. The research highlighted internally developed software that companies use to support CSCD to build an understanding of the field of knowledge and the research challenges and opportunities. CSCD technologies were categorised as communication support, coordination support and cooperation support in this paper that contribute to collaboration. Technologies included; Distributed cooperative design technologies including Lotus Notes, Alfresco, Nuxeo, Zotero, Google Wave; Visualisations technologies including Cimmetry Systems AutoVue, Actify SpinFire, SolidWorks eDrawing, RealityWave ConceptStation, and Autodesk Streamline; PDM and PLM technologies including UGS Team Center, Windchill, ENOVIA VPLM, ENOVIA MatrixOne, and ENOVIA SmarTeam; and Agent based systems and distributed systems technologies including PACT, SHARE, SiFAs, ICM, Co-Designer, Concept Database and A-Design.

Shen et al. use the identification of technology to justify a future vision of CSCD research. The vision includes a fully integrated solution in terms of software integration and physical integration which can be semi-automated, collaborative, secure, personalised – with different access privileges (as is important for industry customers), with knowledge reuse, advice on best practice and supports proactive contribution to the project.

Borsato et al. (2015) documented the considerations of technology selection as part of the Co-ENV project involving 21 Italian companies. The project collected data on the interrelationships between the companies and how they worked collaboratively with co-design tools over one year. The author identified tools within five areas: collaborative CAD systems including technologies such as Oracle Autovue, PTC Co-Create; collaborative portal servers including Microsoft Sharepoint, Mindquerry, Cyn.in and Plone; collaborative PLM suites including cPLM and solutions by PTC, Siemens, IBM and others; digital note software including Microsoft OneNote, Post-it Digital Notes and communication tools including Skype, Elluminate, Messenger and others. From this identification of technology and an identification of the requirements (of which information of the requirements is not divulged) a system was created to support the Italian furniture design sector that includes a virtual catalogue of products, a design configurator, a data manager and Co-Designer functionality for the co-creation of customised products.

All technologies identified from the scoping search, state-of-the-art search and systematic literature search were mapped to identify if multiple papers identified the same technologies. The results are displayed in Appendix 5 and are discussed in Chapter 4.2.3. This list supports the creation of an evaluation and selection method. The literature does not represent all available technology as discussed in Chapter 4.2.3, and more technologies could be found using a different research method.

4.2.3 Discussion on the technologies identified for CSCD

From the literature search, eight technologies were stated in multiple literature sources: Facebook (five sources), Skype (five sources), Blog's (three sources), Twitter (three sources), Email (two sources), Google Drive (two sources), LinkedIn (two sources) and YouTube (two sources). These technologies discussed within the literature support the observations described in Chapter 1 and 2, that has led to the motivation for this research as an observation towards the use of novel technologies.

A general criticism of the research field from reflection on the literature review results is that the reasons to select a specific technology are not commonly reported. This may not have been reported because it is difficult to determine the reasons why, but it is easy to record and report on usage. A systematic method technology evaluation and selection method support justifiable technology selection.

One key challenge was the dynamic nature of technology adoption – the technology landscape changes frequently. Some technologies have been around for many years, and some are new. For example, Skype has offered video conferencing since 2003, and in that time, the functionality of Skype has changed very little. However, other video conference software has launched since such as Zoom in 2011 and Microsoft Teams in 2017. From a functionality perspective, each of these technologies achieves the same goal, video conferencing, and so, why are some technologies more popular and what are the deciding factors in their selection for collaborative design work? By examining the decision-making process using criteria of requirements and functionality, the decision that leads to one technology being selected over another can be formalised.

Hurn (2012), Sheriff (2012) and Sarka et al. (2014) detailed the use of blogs, however, this was not a technology that has been observed used in GDP since 2015 as technologies like blogs have been increasingly replaced with microblogging websites, such as Twitter and social network sites like Facebook. It may seem that a blogging service and a microblogging service are comparable in terms of their functionality, enabling text communication. However, as Gopsill et al. (2014) identified, the key difference is how the message is delivered -it is not simply the content of the message itself.

Shen et al. (2015) and Borsato et al. (2015) reflected on the use of technologies used within an industry setting. The technologies are used for communication, project management and coordination of the team. Technologies such as Product Design Management and Product Lifecycle Management were identified, where the students do not have access to this technology. This could be because the projects are conducted in a limited time within education, and the effort to set up and learn these technologies does not fit within the projects.

4.2.4 Summary

From this literature search, case studies are presented in different but related contexts using different technologies. The research reviewed has highlighted that technology selection is typically based upon the knowledge of the decision-maker in the project, the technologies that are known to these individual and there is generally a subjective criterion for decision-making rather than a systematic and well-considered one.

Due to the dynamic nature of the functionality provided by technology, with new technologies coming to the market regularly, a solution to identify suitable technologies should be agile and dynamic to include new technologies as required; and systematic to document the decision-making process. Moreover, as the technology changes, the method used to create the technology selection and evaluation tool must also be reviewed and updated to ensure it is suitable for the evaluation of the latest tools. It is therefore important that the creation of such a method is well documented.

The technologies used for CSCD identified within the literature provide a foundation to support evaluation and selection, and any additional technologies can be added. These technologies are identified in students use of technology in a GDP as detailed in Chapter 2.

There is still a need to establish how these requirements can be satisfied in using the technologies. For this task, the functionalities of the technologies will be investigated. The requirements are satisfied by particular functionalities of technology, and the functionalities of the technology belong inherently to the technology. This is the missing gap in being able to evaluate and select technologies based upon the requirements of CSCD.

4.3 CSCD technology functionality review

To identify the technology functionalities prevalent in technologies that support CSCD, the literature was searched to find a formal list applicable to CSCD. In this chapter, the process of identifying a list of functionalities is described. The literature found is presented, and comments are made on the significance and appropriateness of the literature found.

The outcome of this chapter is an identification of the technology functionalities prevalent in the CSCD literature. This contributes to the need to formalise the definition of the CSCD technology functionality as a basis for selecting and evaluating the technology.

4.3.1 Search procedure

To identify the functionalities of technologies to support CSCD, a literature approach was created. First, a definition of the scope of the literature search was created (Figure 4-6 – Step 1) followed by the creation of a search procedure (Figure 4-6 – Step 2). The scoping search, state-of-the-art searching and the systematic literature search all influenced the development of an iterative literature search approach towards a preliminary search to establish the relevant search engines and the search string (Figure 4-6 – Step 3-5). Once established, the full search was conducted, and relevant papers were downloaded and analysed (Figure 4-6 – Step 6-7). Citation mining was employed as a technique to identify literature on the creation of technology functionality lists, ontologies, taxonomies and others from the already identified papers that perhaps discussed the implementation of such lists (Figure 4-6 – Step 8). Eight papers were identified which detail eight functionality classification lists. The lists relate to technology functionality in collaborative design, collaborative systems, collaborative engineering and KM (Figure 4-6 – Step 9-10).

Examples were found in the literature that determined how technology requirements were satisfied by using a particular technology, or how a certain functionality of a technology supported CSCD working. However, these examples were not typically representative of the primary research focus of the literature being reviewed.

To ensure a robust literature grounding, there was a need to determine whether a list of technology functionalities applicable to CSCD had previously been created, and if not, to investigate the literature to determine if a list could be created.

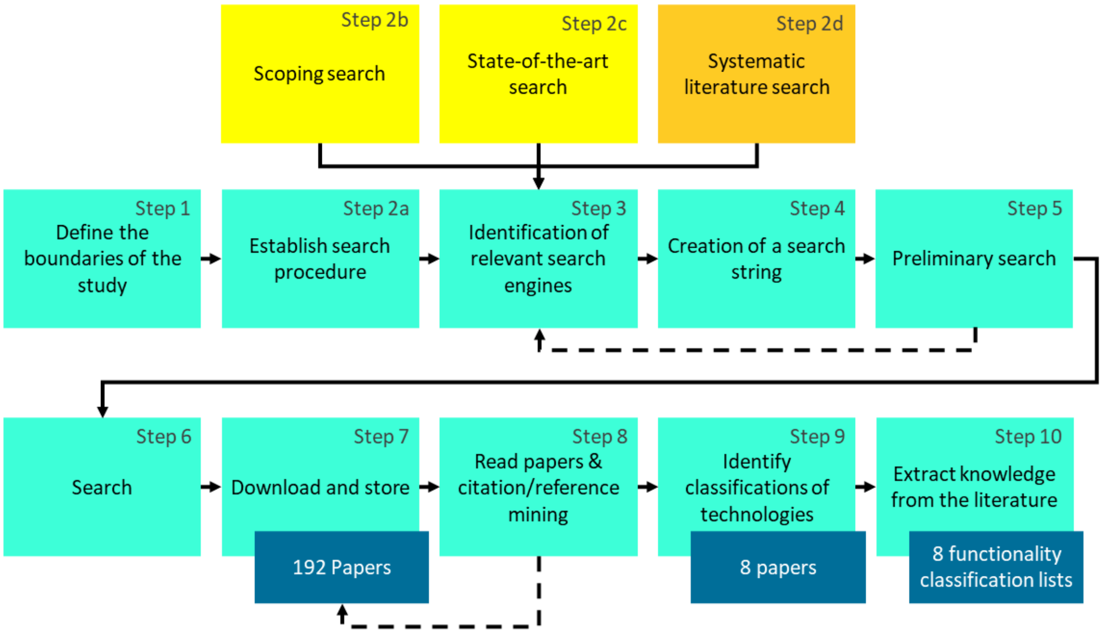


Figure 4-6: Procedure to identify the technology functionalities of computer technology

In searching for lists of technology functionality, the lists identified were general in nature, that could be applied to a range of computer-based issues. Technology functionality is generalisable and it can be applied to specific problems such as evaluating and selecting technology suitable for CSCD. It was decided that these established, peer-reviewed and accepted generalised lists of technology functionalities would be investigated to evaluate if any would be applicable to the identification of functionalities of technology for CSCD.

A search procedure was established to find relevant papers indexed on search engines using the keywords "Functional*" AND "Technolog*" AND ("Ontology" OR "Classification" OR "Taxonomy"). The search engines used included ProQuest, Engineering Village, IEEE Xplore, Scopus and Google Scholar.

As papers were discovered, they were reviewed and added to a library using literature management software Qiqqa (qiqqa.com). The exclusion criteria of accessibility, written in English and peer-reviewed were applied. This search also relied on chain searching and citation mining to identify if a paper referenced another that claimed to publish a list of technology functionality. This search was performed in February 2018.

From the 192 papers identified in the literature as a result of this search, eight presented lists of technology functionality. The majority of papers found reported the practical use of lists, ontologies, taxonomies of technology to identify or classify novel technologies, rather than the development of new classification lists.

4.3.2 Review of the literature on technology functionality classifications

Mika & Akkermans (2004) conducted research into the state-of-the-art technologies for Knowledge Management (KM) within a business context, producing a classification framework and application scenarios of ontology technology (formal models of technology) and KM. In developing the framework, Mika & Akkermans identified 15 technology factors within a general architecture of ontology-based systems. These factors are: search, browse, visualise, share, store, transform, reason, secure, version, transfer, extract, learn, edit, merge, evaluate and annotate. The factors can be considered to be analogous with the functionalities of the technology. The focus on KM means that the factors have a lack of consideration of how the user may utilise them, or how it helps them achieve their goals. CSCD is inherently about supporting collaborative design using computer technology, and so all factors may not be suitable.

Koch & Gross (2006) investigated groupware's support of CSCW in the context of requirements engineering. They reviewed groupware literature and identified issues with functionality of tools and aligned them with an adapted functional categorisation from Borghoff & Schlichter (2000). The categorisation categories were: awareness support; communication support; coordination support; team support; and, community support. This classification is high level and does not provide specific detail of the functional support despite utilising a functional categorisation, and is more analogous with technology requirements within a computer science context than functionality.

Ostergaard et al. (2003) investigated the communication issues associated with the use of collaborative design tools in engineering. The purpose of the investigation was to direct and improve the development of digital collaborative design tools. A taxonomy was created for communication methods within collaborative design that identified 26 influences for collaboration across six categories of: team composition (group, individual, team member relations, leadership style, mode,); communication (quantity, syntax, proficiency of team, dependability of resources, intent,); distribution (personal, informational); design approach (design tool applied in each phase, evaluation of progress, degree of structure, process approach, stage); information (form, management, perceived level of criticality, dependability of information); and, nature of the problem (type of design, coupling of sub-tasks, scope, complexity). The methodology used to create the taxonomy was not described by Ostergaard et al., raising concerns in relation to the completeness and reliability of the categories. The six categories were however similar to those reported by Mattessich & Monsey (1992), suggesting that the outcome of this research has agreement with published literature.

Other authors have built upon the work of Ostergaard et al. (2003) to develop the taxonomy for other purposes and to improve the reliability. Ostergaard & Summers (2007) developed the taxonomy by proposing a model of information flow and resistance, focusing on transfer of knowledge which is only one aspect of collaboration. The model was evaluated using case studies, however an assessment of its impact was not determined at the time of its publication. Ostergaard & Summers (2009) further developed the taxonomy using literature for the purpose of classifying collaborative design situations. An additional 29 subfactors are presented with their dependencies on each other.

Finally, Righter et al. (2017) aimed to determine the application of Ostergaard et al. (2003) taxonomy from case studies reported in the literature. 24 papers were selected with case studies reports and these were evaluated against the taxonomy. Righter et al. determined that the frequency of level 2 and level 3 collaborative design characteristics reported in the literature was low (19 of the characteristics within the taxonomy were identified within less than 20% of the literature investigated). Righter et al. subsequently suggested that improvements were required to the taxonomy, including the consistency of reporting, and a shared understanding of the definitions of the characteristics.

Gutierrez et al. (2013) shared findings in relation to a student's use of an online discussion board technology within a business school. Students were asked to perform a factfinding activity and share results with other students using the online discussion board. Using two case studies of technology use in a student project, Gutierrez identified nine functionalities of an online discussion board similar to those used by students on social network sites. The functionalities identified were: contribution (a description of the information the students had found and were sharing); participation level (meta-information about the student's role in the case studies and how many students were participating); search bar; category (keywords); detailed view (to expand the contribution for more details such as URL link to the original article); tag cloud (with keywords listed as different size, a larger font means more contributions); rating a contribution (to score others contribution); and comments. This list of functionalities was based on the use of a discussion board technology and the generalisation of this list may not be suitable for other technologies.

Mittleman et al. (2015) created a classification of collaboration technology that was analogous with a taxonomy of collaboration technology functionality. This list was created from studying the use of 'groupware' technologies and determining the core competencies of the technologies, which may be considered to be synonymous with technology functionality. Mittleman identified three categories of core competencies of collaboration technologies with 11 subcategories. These categories were: jointly authored pages (shared editors, dynamic group tools, conversation tools, polling tools); streaming media (desktop/application sharing, audio conferencing, video conferencing); and information access tools (shared file repositories, social tagging systems, search engines, syndication tools). This classification list can be applied to current technologies with web 2.0 functionality such as collaborative document editors, video conferencing, data storage and social network sites. Further investigation is required to understand what technologies are used by CSCD teams, to determine if the core competencies provided by Mittleman et al. or any other lists, are appropriate for use in evaluating technology functionality.

4.3.3 Summary

These eight categorisations identified from the literature highlight different ways of considering technology functionality for different contexts. As no specific list was identified for CSCD, further investigation is required to determine if an existing list would be suitable to link the requirements of CSCD, with the technologies that support CSCD. Although no specific CSCD list exists, the lists created on collaborative design may be suitable and requires further investigation, or if further research is required to create a new list of technology functionalities for CSCD.

The eight lists of technology functionality can be summarised in six themes based on the nature of the work. These are: knowledge management for engineers, CSCW for requirements engineering, collaborative engineering design, collaborative design, collaborative teamwork in education and collaborative systems.

A summary of the lists is included as Table 4-5 that can be used to support the decision to identify which list is most appropriate to represent technology functionality for CSCD. This will be further discussed in Chapter 6.

Table 4-5: Lists that identify technology functionality

Title of paper and author	**Nature of the work**
Towards a new synthesis of ontology technology and knowledge management (Mika & Akkermans 2004).	Knowledge management for Engineers.
Computer-Supported Co-operative Work – Concepts and Trends (Koch & Gross 2006).	CSCW for requirements engineering.
A Taxonomic Classification Of Collaborative Design (Ostergaard et al. 2003).	Collaborative engineering design.
Development Of A Systematic Classification And Taxonomy Of Collaborative Design Activities (Ostergaard & Summers 2009).	Collaborative design.
Resistance Based Modeling of Collaborative Design (Ostergaard & Summers 2007).	Collaborative design.
Literature-Based Review Of A Collaborative Design Taxonomy (Righter et al. 2017).	Collaborative engineering design.
Analyzing Two Participation Strategies In An Undergraduate Course Community (Gutierrez et al. 2013)	Collaborative teamwork in education.
Collaboration Systems concept, Value, And Use (Mittleman et al. 2015)	Collaborative systems.

4.4 Characteristics of a technology evaluation and selection method

From the motivation and preliminary investigation within the GDP class, there was a requirement to investigate if a method of technology evaluation and selection exists that is suitable for the students of the GDP to support CSCD teamwork. If a method is found, its suitability for CSCD should be evaluated and implemented. If a method is not found, then the characteristics of developing such a method should be established. If methods of technology evaluation and selection are found in related fields such as collaborative design, but are not suitable for CSCD, lessons can be derived about the methodology of their creation that will influence this research.

The procedure of this literature search is detailed in Figure 4-7. First, the boundaries of the literature search were created based upon the aim to identify technology evaluation and selection methods (Figure 4-7 – Step 1). A literature search was conducted with this specific focus (Figure 4-7 – Step 2a) supported by the state-of-the-art search and the scoping search (Figure 4-7 – Step 2b&c). All literature was collected and analysed as described in this chapter (Figure 4-7 – Step 3 & 4) and the outcomes were extracted from the literature (Figure 4-7 – Step 5).

A literature search was conducted focused on finding technology evaluation and/or technology selection methods that could support the evaluation of the technologies to support CSCD teamwork. Keywords used for this search were “Technology” OR “Computer Supported” AND “Selection” OR “Evaluation” AND “Engineering Design” OR “Collaborative Design” OR “Product Design”. The search was conducted on ProQuest, Engineering Village, IEEE Xplore, Scopus and Google Scholar. Literature was identified that contributed towards an understanding of methods technology evaluation or selection for collaborative engineering design teams.

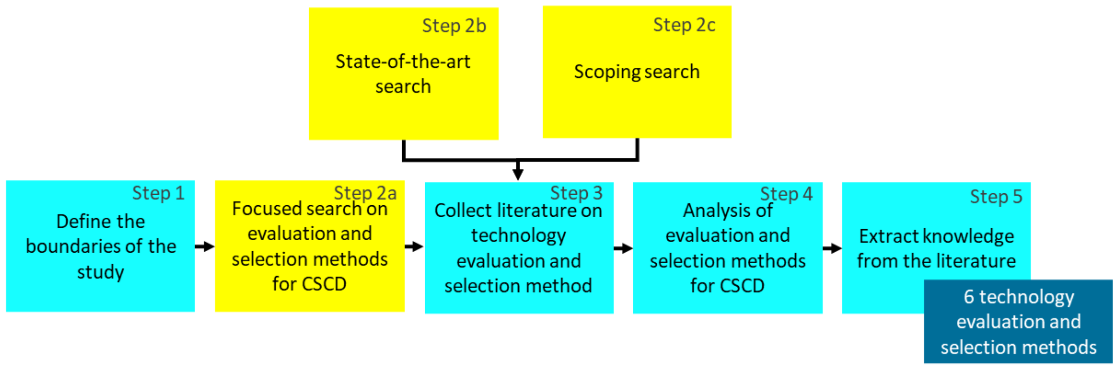


Figure 4-7: Procedure to identify the technology evaluation and selection methods

Within this section, the published literature on technology evaluation and selection methods that can be applied to collaborative engineering design teamwork is discussed. The methods are compared against each other, and the gaps in the knowledge are reported.

4.4.1 Considerations of technology evaluation and selection method

Technology evaluation and selection methods have been developed to support engineering design teams across the years. Within these papers, there is a mixture of methods proposed for different purposes. Each of the methods is discussed individually to highlight their use, and strengths and weaknesses.

Technology evaluation and selection tools practically support teams or decision-makers to make informed determinations about the technology they chose to use. If the correct technology is selected, it can have many benefits such as: an increase in innovation performance that has been attributed to technology selection; a company's technology capacity and technology management capacity (Hao et al. 2007); provide more collaborative methods of communication for a design team (Gopsill 2014); or to minimise risks associated with the performance of a team affecting project objectives (Rassias & Kirytopoulos 2014).

Torkkeli & Tuominen (2002) highlighted the importance of ensuring the right technologies are in place, stating: "A company can waste its competitive advantage by investing in wrong alternatives at the wrong time or by investing too much in the right ones". It is then logical for a decision-maker such as a manager to take steps towards successful technology selection. Singh et al. (2013) highlight some of the reasons for technology selection, stating: "Managers tend to adopt new technologies due to the benefits announced by other companies across the world or customer demand or change in taste of the clients. It is understood that managers must be aware of those change in the market and make a right decision of implementing such advanced technologies in their organisations processes and production technologies." These two authors suggest that managers are slow to react to technology changes or that there is too much investment in unsuitable alternatives. Technology selection support is required that allows a faster evaluation of the technology.

Over time, selecting appropriate technologies has become increasingly difficult as highlighted by Torkkeli & Tuominen (2002), "It is more and more difficult to clarify the right technology alternatives because the number of technologies is increasing, and technologies are becoming more and more complex". This sentiment is still relevant today as the number of new computer-based technologies increases each year. When considering technology selection methods, it is vital to contemplate the large range of potential technological solutions and functionalities that can support a project (Gibson & Cohen 2004).

The majority of the methods for technology evaluation and selection identified in the literature from the literature search were based upon Quality Function Deployment (QFD) and a part of the QFD process known as House of Quality (HoQ). The purpose of QFD in systems engineering is to capture the voice of the customer to inform the characteristics of a solution e.g., the opinions of a customer on a future product to determine the requirements specification of that product in product design.

Methods of technology evaluation and selection methods identified from the literature used a HoQ tool or similar, or augmented method to evaluate technologies against criteria. The complexity of these methods differs with some developing up to a seven step/seven matrix approach. Each of these approaches is described in the following section.

4.4.2 The literature on technology evaluation and selection identified

Germani et al. (2012) documented the creation of a method for benchmarking co-design tools. The purpose of the method was to identify an effective and easy to use co-design system for SME's. The method is created by formalising the product development process of SME's involved in the research using IDEF0 and Unified Modelling Language (UML) techniques that led to a QFD based approach.

The research was facilitated through CPD with 21 Italian SME and LME companies conducting interviews, questionnaires and observation. The consortium of companies was headed by three leader companies in; woodworking machinery manufacturing, household appliances, and wellness products.

The benchmarking method developed compares collaboration tasks with co-design functionalities. Both appear to be derived from the 'formalising the product development process of SME's,' however, little information of the author's procedure and rationale for the development of these categories is detailed. The criteria is based upon real-world company practices. However, the breadth and accuracy of the researcher's conversion of the data from the companies held in interviews, questionnaires and observations cannot be determined. It is not clear how this data was converted.

The developed benchmarking method uses 714 comparisons between the collaboration tasks and the co-design functionalities that would take considerable time to populate. A decision has to be made for each of these comparison points to apply a score to the i.e. how well the co-design functionality satisfies the collaboration tasks. A weighting is also applied that details how important the collaboration task is to the company workflow. The co-design functionalities are totalled and compared with co-design tools to determine a toolkit. It is unclear what purpose the collaborative weighting plays on the co-design functionality score as the tools selected to support all functionalities. Perhaps a simple yes/no to the question, 'is a co-design functionality required' would suffice, then a score could be added at the tool side if there are multiple tools with similar functionalities to determine the best tool to select.

The benchmarking method created influenced the design of a co-design software that features shared product documents, project and workflow management, technical data storage and distribution, product collaboration space and project results. The author claims that the software developed with the functionality identified satisfies the needs of the 21 companies This software is evaluated by two of the companies involved in the consortium and the software functionality appears to be the same for both. It is then unclear why an effort was made to create a benchmarking co-design tool that could determine custom software based on the requirements of the individual 21 companies. A more straightforward functionality requirement method may have produced the same results.

Elfving & Jackson (2005) described the creation of a model for evaluating and improving collaboration. The model is based upon principles of collaborative product development between small size companies by recognising the critical tasks for collaboration. These tasks are: mutual strategy and common goals, the importance of requirement specification, trust, functional communication tool, and a dynamic product development process that can adapt to the company.

The focus on small size companies includes considerations of external stakeholders going beyond the core engineering design team, such as main and sub-supply chain stakeholders. The authors present the argument that the findings would apply to smaller projects within larger companies that may be the case. However, the focus on industry applications means that the outcomes would not be fully applicable to student teams in an educational environment.

The model of evaluation and improvement was represented as a typical HoQ with a single comparison matrix to compare two sets of factors. The factors for comparison were the type of project, five types are identified, and the five principles of collaborative product development. There is also an outcomes box to highlight the best practice identified.

The roof of the HoQ is used to compare factors against each other. However, it is unclear why knowing that, for example, shared vision and trust are linked when populating the matrix. Indeed, these two principles are linked, and they are important to each other from a theory standpoint, but having one does not mean that the other is satisfied, or that both are required at the same time. They are independent of the standpoint of satisfying the requirements of collaboration.

The model was tested within an enterprise case study employing a large mechanical and mechatronics company. The research was conducted in parallel to CPD to address difficulties with managing collaboration between the production and the design departments. No information about the number of employees involved or for how long is detailed in the paper. Elfving & Jackson (2005) conducted interviews with company experts with a range of experience, including managers, projects leaders and participators and what is referred to as internal evaluators.

Feedback from company experts included: “there is a need for both fewer and more measurable goals … the preparation must not be more complicated than specifying a checklist”, indicating that both the setup and use of the evaluation and improvement tool had opportunities to be simplified. This perhaps relates to the roof of the HoQ capturing knowledge that does not appear to have any practical use. It might also relate to the definition of the critical tasks that are lacking definitions within the tool itself. However, it is unclear how the tool was presented to the company and the level of detail presented before use.

It was also suggested that human input into the population of the matrix takes time and effort becoming one of the barriers for use by the company. There are 75 individual connections between the type of project and the critical tasks, plus five boxes to collect the best practices, and the roof of the HoQ. Presuming a discussion between team members should be facilitated for each connection of around five minutes, this could amount to over six hours of work for the main evaluation and improvement matrix alone. Not to mention the work to ensure that the team understands the model, motivation when the task becomes repetitive, and increased cognition. For such a high cognitive task, the time to complete should be reduced to encourage completion and fatigue. If this time to populate could be overcome by reducing criteria or some form of automation, the tool would be more attractive for a wider range of users and could have a higher impact.

Pugliese et al. (2004) discussed the development of a technique that enables the integration of new methods and tools within a product design process. The methodology achieves this by considering the product development process and “critical aspects” of this process, and comparing these with knowledge on emerging technologies that an engineering team may have. The work of Pugliese et al. focuses on the context of knowledge management for engineering teams. The first matrix in the process compares the knowledge management activities with the product development activities. This produces the importance score (valuation) of each knowledge management activity that acts as a weighting of importance. The second matrix compares the knowledge management activities with technology functionalities to determine the importance score of the technology functionality (again as a valuation/weighting). Finally, technologies and their technology functionalities are compared to determine a ranking of technologies.

The technique is based on HoQ to compare across three separate matrices. As such, the author has decided to adopt the importance score to multiple the results of the valuation as a form of weighting on the importance of the activities and functionalities. It is not clear why this weighting is required as the knowledge management activities presumably based upon observations of successful knowledge management are all important requirements that must be satisfied.

Mamo et al. (2015) conducted a study to understand the preferred tools for collaboration by globally distributed design students, at different universities, working on the development of a product. Through the management of different student skillsets and institutional backgrounds enable the distribution of work with the purpose to identify that the right technologies with the right design team skills are used at the right time. The author determined the procedures the student used to conduct design activities and which online tools supported the design activities in a global design project. A survey of teams who participated in the global design projects was distributed electronically.

A table is used to display the data of the different design activities that were used and the number of teams who conducted the design activity. As an example, it was identified that nine teams (69% of teams who conducted QFD) populated a quality function deployment in the development of their product in locally distributed groups and later shared the results with other distributed team members. In comparison, brainstorming sessions were reported by nine teams (64% of teams who conducted a brainstorming activity) in distributed synchronous video conference sessions; and nine teams (60% of teams who conducted CAD) reported that CAD was created by one team member and results shared with others.

In understanding the use of design tools and collecting information on the technologies that supported the use of design activities, a design methodology was created for global design student collaboration. This methodology is based upon the data from the 2015 global design projects and, as such, is only applicable to this year of the class as newer technologies may be released and requirements of student collaboration may change. The research work provides a snapshot of the collaboration practices at the time however is not updatable as newer technologies and technology functionalities are developed and as requirements for collaboration change. A method for evaluating suitable technologies should be updatable through good documentation of the creation of the method and systematic automation to support the use of the method.

McAlpine et al. (2011) presented a method to select a technology or tools to support the capture of design information in design situations. This was achieved by comparing the technologies or tool available such as video camera, mobile phone, LiveScribe Pen, tablet PC, and computer-based sketching activities; against four criteria: autonomy; processing required; ease of analysis; and capture & storage cost. These four criteria represent the evaluation criteria of the technologies towards the requirements of the system.

A pragmatic approach was selected to evaluate the technology through three, one-week design exercises using different technology combinations. The researcher observed using these technologies in three separate design projects related to the development of a product or the development of a manufacturing process for a product. 68 hours of data were captured that totalled 14GB of data. This accounts for a substantial amount of input data that is required for this type of study. The author asserts that a neutral third party was used to analyse the coding scheme suggesting no bias was introduced. However, in categorising the data, the author may have categorised their own opinions, which would have introduced bias. It would have been more robust to have multiple coders agreeing on the coding taking place.

The outcomes of this research were a pragmatic guide to selecting appropriate knowledge capture technology. The author admits that this would only allow for the narrowing down of the technology options and would not result in a final chosen technology as technical considerations are not considered by the guide. To produce a more robust selection method, there needed to be more investigation into the requirements of the types of designers who might use these technologies and for what purpose.

Walter et al. (2016) presented the development of a method that supports the comparison of and selection of an appropriate tool for synchronous communication and collaboration in distributed teams. The model developed is in the form of a matrix, that allowed the comparison of tools available, with generic features of tools (aka functionality of tools of which 30 are identified), and then a comparison with actions of a team (13 actions are identified) or group member characteristics (analogous with requirements of which two characteristics are identified). The generic features, actions of a team and group member characteristics are adapted from the paper by Albers et al. (2014) who used a survey to elicit an understanding of product engineering activities for existing companies that suggests the focus on locally distributed product development. Generic features of tools include: enable text-based communication, enable voting's and support file exchange. Actions of a team include presenting electronically stored content, creating/editing sketches and evaluating alternatives. Furthermore, group member characteristics can either be of low degree of familiarity or different kind of expertise required. It is unclear why more options are not linked with characteristics of teams, such as a high degree of familiarity. Moreover, perhaps if the model were to be developed for global teams, there would be a need for characteristics such as global displacement, time zones, culture and other team characteristics.

Walter et al. (2016) highlighted that the use of the tools is influenced by team member behaviours and their nature. This is an important aspect of technology selection, and evaluation as different teams may use technologies in slightly different ways, which would alter the outcomes of the evaluation process.

The method presented by Walter et al. resembles a rearranged HoQ with two mapping areas. The first mapping area compares the generic features against the actions and characteristics of the team, and the second mapping area then compares the generic features with tools available. The first matrix is then compared with the second to identify the most appropriate tool. There is no evaluation of the model.

4.4.3 Lessons from the published literature

Within the technology selection literature, the research conducted has focused on using a matrix-based solution commonly inspired by the HoQ or QFD approach. However, each method within the literature only goes so far as to identify a suitable approach. This section will discuss some of the shortcomings of the methods identified and their suitability towards the motivation of this research.

The HoQ approach presented by Germani et al. (2012) uses metrics established during a holistic experimental approach and have not been verified or validated. The lack of detail in creating the list of collaboration tasks performed by the companies and the co-design functionalities that they perform, means that the approach cannot be replicated with respect to CSCD tasks and CSCD functionality requirements.

Some approaches would have produced a suitable level of detail, such as, the use of an established and renowned peer-reviewed list that is comprehensive to the problem area and built upon existing knowledge, or a more robust documentation of the conversion of data collected by the author and coded into the lists of collaboration tasks and the co-design functionalities. This may have been achieved using an established coding method as demonstrated in McAlpine et al. (2011). However, multiple perspectives are required to reduce the bias in the coding process and ensure correctness.

The methods developed by Germani et al. (2012) and Elfving & Jackson (2005) require an in-depth knowledge of both collaboration theory and company practices. A company's data can be captured through interviews, surveys, observations and other methods as demonstrated. Both research projects identify a need to have direct contact with the team who are conducting the work, and Mamo et al. (2015) who demonstrated that the same is required when investigating collaboration of student teams.

Walter et al. (2016) built an understanding of the factors that influence collaboration and technology selection by using pre-established literature published by Albers et al. (2014). Walter et al. determined that the research that had come before was suitable for the purpose of their research, it was well established and would provide the required outcomes when implemented into a practical tool for evaluation and selection of technology

Pugliese et al. (2004) had a focus on knowledge management rather than collaboration, establishing a technology evaluation and selection method. Key to the success of this method was a grounding of the KM activities and knowledge functionality within theory. An IDEF0 model supports the logical development of the method supporting clarity in how the author made decisions in developing the technology selection method. The model represents how each aspect of KM activity, process activity, knowledge functionality. Later in the paper by Pugliese et al. (2004) once the method is established, it is clear why the three matrices are required that are supported by the theory of how the different aspects are connected.

The method presented in McAlpine et al. (2011) supports a robust research approach, building upon existing research and creating a novel approach. The method presented utilised a coding process that, if well documented, is a robust way of producing outcomes from a literature search and literature review. The method enabled an automated population of the tool that is useful for teams who do not have the time to populate the outcomes of the method, or where the experts in the process are not also the experts in collaborative design theory. This is an important aspect of such a tool that can support accessibility and, therefore, the usefulness of the technology evaluation and selection tool. Without an automation component, potential users may be discouraged from utilising the tool and resort to less robust methods.

In searching the literature for methods of technology evaluation and selection, no method was found that could be used to evaluate and select technologies for CSCD student teams, as is the motivation of this research. Methods were found that are built upon knowledge of; collocated teams who do not use technology or communicate in the same way as distributed teams, industry practice of a design company that introduces aspects of supply chain and manufacturing management, knowledge capture that is only one aspect of collaboration as a part of knowledge management, a specific use case or is limited in other ways i.e., temporally by year.

From these limitations, there is an identification of what has been successful for other authors. Germani et al. (2012), Elfving & Jackson (2005), Walter et al. (2016), and Pugliese et al. (2004) all utilise QFD or HoQ, demonstrating that such an approach is appropriate to produce technology evaluation and selection methods.

A method related to Computer-Supported Collaborative Design was not identified in reviewing the literature on technology evaluation and selection. Table 4-6 highlights the characteristics of the methods identified in the literature

Towards the motivation of the research, the method that has the potential to support students of the GDP class to evaluate and selecting relevant technology is the method presented in Germani et al. (2012). The method presents a benchmarking method that enables technologies to be compared with each other. Benchmarking is useful upon the implementation of a technology within a context but unfortunately cannot act as a prediction of the suitability of technology that is important for new teams or new projects without established technologies.

Walter et al. (2016) present the most accessible method for the students of the GDP as the purpose is to improve collaboration practice in a distributed product development context. Walter et al. only refer to factors of collaborative design related to synchronous product development activities and coordination, where CSCD is related to both the synchronous and asynchronous modes of communication, plus other aspects of collaboration related to coordination and cooperation.

Table 4-6: Technology evaluation and selection methods for designers

	Germani et al. (2012)	**Elfving and Jackson (2005)**	**Pugliese et al. (2004)**	**Mamo et al. (2015)**	**McAlpine et al. (2011)**	**Walter et al. (2016)**
Topic Focus	Design Activities	Functionalities of Technologies	Functionalities of Technologies	Technologies	Technologies	Design Activities
Aim	Benchmarking (Performance)	Best Collaboration Practices	Improve Knowledge Management	Best Collaboration Practices	Best Collaboration Practices	Improve Collaboration
Peer Reviewed Metrics from literature		Collaborative Product Design				Synchronous Product Development
QFD Inspired	X	X	X	X		Similar to HoQ
Automated					X	
Evaluation		X				
Level of knowledge required on Collaboration	High	High	High	Low (Based on project data)	Medium (Coding Schema)	Low (Actions and features defined)

Upon reflection of the suitability of the existing methods of technology evaluation and selection, there is a need to take the lessons learned from the successful development of technology evaluation and selection methods as discovered in the literature and to build upon this knowledge with a method relevant to the task of evaluating and selecting technologies that support CSCD.

4.4.4 Establishing conditions to support technology evaluation and selection

From the identified literature, no technology evaluation and selection method were identified that were suitable for the GDP students to conduct CSCD project work. Where there may be similarities between the requirements of collocated collaborative design, knowledge management, synchronous distributed design and the requirements of CSCD, they are distinctly different modes of working. There may be a greater or fewer number of requirements in total, and the importance of these requirements may be different for modes of working.

Five of the six methods identified for technology evaluation and selection were based upon the QFD and/or implemented a HoQ tool or functionally similar tool. The HoQ tool uses a comparison of characteristics to determine if concepts are related. Applying this logic to the evaluation of technology, the requirements of a CSCD project are characteristics to be satisfied by the functionalities that technologies can offer. The comparison of technologies and the functionalities these technologies have can also be represented in this way.

In order to evaluate and select technology for CSCD there is a need to establish if the requirements of CSCD have been satisfied by the technology functionalities, and there is a need to identify how these functionalities can satisfy requirements. The understanding built in this literature search and review chapter contributes towards this, and is further developed in Chapters 5, 6 and 7. In parallel, there is a need to determine the relationships between technology and functionality which is explored in Chapters 6 and 7.

4.5 Summary

This chapter presents a literature review with the aim of determining a gap in the knowledge that can be filled by the research presented within this thesis.

The requirements of CSCD were investigated to determine if a list of requirements of CSCD existed, published in the literature, no single list existed, however many papers were found that contain individual requirements of CSCD. The 220 requirements were compiled and will be further developed into a list of requirements for CSCD in Chapter 5.

The technologies used for CSCD were investigated and 62 were found in the published literature. However, a consensus was not found in the published work with few technologies being reported in multiple papers. In addition, there was a significant difference identified between technologies reported in student projects and those reported in industry projects. The work presented in Chapter 2 on technologies used in the GDP can be used to create a reasonable list of technologies for technology evaluation and selection, however, this represents technologies known at a particular moment in time and may not be suitable for future CSCD projects. Further analysis is required to determine if the technologies identified in this literature search and review are suitable for use in a technology evaluation and selection method as described in Chapter 6.

The technology functionalities were investigated and eight lists of functionalities of technologies for CSCD were identified. It was inconclusive if any lists were suitable towards a method of evaluating and selecting technologies for CSCD and further analysis of these lists is required. This is described in Chapter 6.

The final investigation detailed in this chapter aimed to confirm the gap in knowledge of a technology evaluation and selection methods for CSCD. The results were the identification of six research publications relevant to the aim of supporting technology evaluation and selection in benchmarking (Performance), best collaboration practices, improve knowledge management or for the purpose of improving collaboration. None of the identified methods was identified as suitable for CSCD as they were designed. Similarities between the methods of, and barriers to their use were identified to establish best practices to support technology evaluation and selection from the literature. It was determined that a technology evaluation and selection method would be created to support GDP students to conduct CSCD projects. This is described in Chapter 6.

5 THE REQUIREMENTS OF CSCD

The purpose of this chapter is to verify and validate the requirements of CSCD as identified in the literature and in support of a technology evaluation and selection method, to categories the 220 requirements of CSCD identified in the literature and create CSCD requirements statements that represent each category. The categories and the CSCD statements are the outcomes of this chapter that are required to support the creation of the CSCD matrix reported in Chapter 6.

The 220 requirements of CSCD identified in the literature, within Chapter 4. Represent the known requirements. To ensure these requirements were accurate a verification was conducted using workshops with experts in CSCD. Participants in these workshops were asked to identify the factors which contribute towards collaborative design success and failure, and to collate these factors into categories. The factors identified can be compared to the requirements of CSCD to identify if there are any requirements of successful collaboration which may be missing. The workshops will support the identification of any missing categories, and that the requirements of CSCD were accurately categorised, verifying both the requirements and the categorisation.

Following the verification of the categorisation, the requirements were transformed into CSCD requirements statements. These are sentences that represent all requirements within a particular category. This was conducted to make discussing the requirements easier as part of a technology evaluation and selection method i.e., 19 requirements statements to discuss CSCD requirements rather than 220 individual requirements. A significant reduction in time and comprehension of collaborative design influences is required.

The statements were validated using a survey of experts in CSCD. Participants responded if they agreed, disagreed in full or disagreed in part with each of the statements and provided rationale. This feedback from experts was used to redevelop the CSCD requirements statements when required and to rank the statements in order of importance.

Figure 4-2 continues the steps in the process from Figure 4.2 which demonstrated the process of reviewing the literature to identify the requirements for CSCD. Three workshops were conducted with experts in CSCD to verify the 220 requirements and determine a categorisation schema (Figure 5-1 – Step 11). Categories were established iteratively (Figure 5-1 – Step 12-13), and requirements statements were created based upon the categorised requirements. 19 sub-categories were created (Figure 5-1 – Step 14), validated by experts using a survey (Figure 5-1 – Step 15), and updated to reflect comments from the experts. 19 requirements statements were created following the updates (Figure 5-1 – Step 16) and used as a basis to support the development of the evaluation and selection approach.

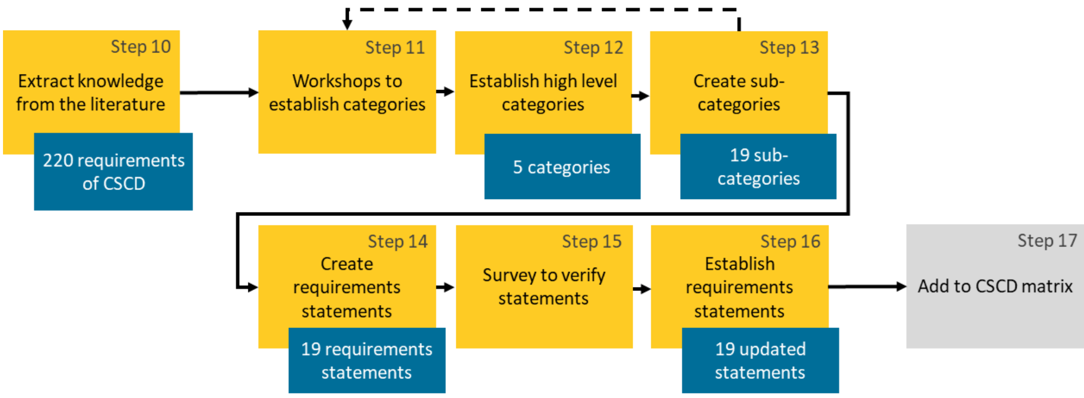


Figure 5-1: Methodology to identify the requirements to support CSCD

5.1 The categorisation of CSCD requirements

In Chapter 4, a gap in knowledge was established, that a technology evaluation and selection method did not exist. To support the development of this method, the requirements of CSCD were found from the published literature. However, there were two issues to resolve.

First, the requirements collected from the literature were complete in terms of the published literature, however, there may be other requirements that are not published. The requirements of CSCD identified in the literature require verification to manage bias in performing the categorisation. And secondly, in analysing the literature there was a motivation to identify common themes in the requirements. Themes were identified if multiple authors identified the same requirements to simplify the list. This categorisation also requires verification to ensure requirements are categorised accurately.

5.1.1 Initial categorisation of the 220 requirements for CSCD

The first step in the categorisation was to align the 220 requirements from 27 papers into the six categories of requirements presented by Mattessich & Monsey (1992) represented in Figure 5-2. These are: communication, environment, resources, membership characteristics, process and structure, and purpose. Note that the category of *purpose* was later removed as detailed in Chapter 5.1.1. This categorisation by Mattessich & Monsey was chosen as it was the highest cited work in the context of collaboration within the literature reviewed. This formed the higher-level categorisation and further sub-categories emerged from the categorisation.

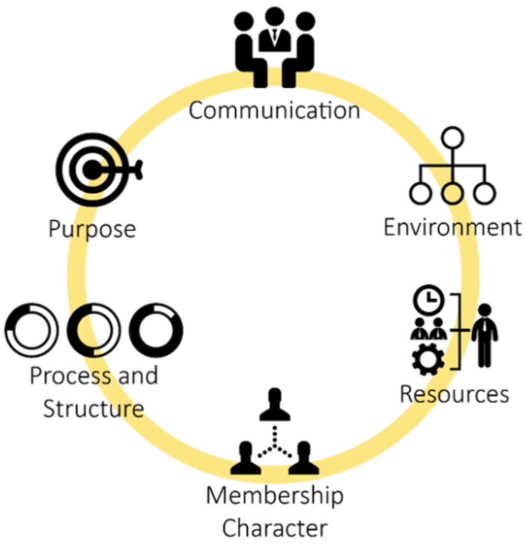


Figure 5-2: The categories of collaboration adapted from Mattessich & Monsey (1992)

NVivo 11 software (www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home) was used to create the coding scheme. NVivo was used to read and assign keywords to the requirements. The first categorisation was created by the author, and subsequent re-categorisations were performed as a result of outcomes from workshops as described in Chapters 5.1.1 through 5.1.3. NVivo was used to check the original context of the requirements and recode the categories and sub-categories as required.

To provide an example of the thematic categorisation, the following requirements identified from the literature all relate to artefacts or representations:

- Allow response with high quality **representation** examples - Gopsill et al. (2014);
- Allow for the addition of **artefacts** to text-based ideation - Herrmann et al. (2013);
- **Artefact**-mediated interaction - Vyas et al. (2012);
- Incorporate **artefacts** into the online design space - Vyas et al. (2010); and,
- Provide an **electronic or physical reference** for communication - Gopsill et al. (2014).

By reading and understanding the context of access, the requirements were added to the categorisation of collaborative requirements presented by Mattessich & Monsey (1992) as *communication*. This is because the artefact or digital representations is used to support communication. A sub-theme was created named “artefacts” for these five requirements.

The sub-categories created initially were:

1. Artefact-mediated communication
2. Feedback from stakeholders
3. Social communication
4. Overcome boundaries of access
5. Integration with company structure
6. Decision making
7. Knowledge capture
8. Greater productivity
9. Commonality (reduce barriers)
10. Motivation
11. A shared understanding
12. Cooperation
13. Building of trust
14. Development of greater competency
15. Coordination
16. Innovative thinking
17. Knowledge management
18. Technological factors

Note that the technological factors sub-category is later split into two categories of *communication* and *sharing of data* as detailed in Chapter 5.1.2.

5.1.2 Workshops to verify the requirements of CSCD and categorisation

Following the initial categorisation of the 220 requirements, workshops were conducted with the aim to identify any missing requirements and to verify the categorisation. The outcomes of the workshops were an identification of factors that contribute towards collaborative design success and failure, and a categorisation of these factors. These factors and the categories were compared to the 220 requirements of CSCD and the initial categories to determine if there are any missing.

This approach was chosen in comparison to presenting the requirements and having them approved to reduce bias in the initial categorisation. The categorisation is later validated using a survey as described in Chapter 5.3.

Three workshops were organised at academic conferences with academics that were experienced with CSCD. The conferences were: the 18th International Conference on Engineering and Product Design Education (E&PDE 2016) with 12 participants; the 21st

International Conference on Engineering Design (ICED17) with 22 participants; and, the 15th International Design Conference (DESIGN2018) with 21 participants. The workshops are described in more detail within Chapter 5.1.3 to 5.1.5.

Although the activities that took place at each of these workshops changed, the question asked at each workshop remained the same: "what are the *factors which contribute towards collaborative design success and failure"* Following each of the workshops, the categorised requirements were compared against the outcomes of the workshops to identify if there were any missing requirements, missing categories or differences in categorisation.

5.1.3 E&PDE 2016

During the E&PDE conference in 2016, workshop participants were asked to attend and discuss the factors which contribute towards collaborative design success and failure within product design education using technology. The attendees all had experience teaching in a collaborative educational environment using technology or had been involved in global design projects. The group were supplied with sticky notes, pens and paper to facilitate a group brainstorming session. Attendees were split into two groups of six and conducted the identification of challenges in their groups. The categorisation was initially conducted in groups and then the groups came together to form a combined list of the challenges and categories. Photographs were taken to record the knowledge creation.

The group identified six high-level categories of teamwork, distributed solutions, tools, and time management. The categorisation that emerged was teamwork, distributed solutions, tools, time management, project management and cultural.

The participants were then asked to assess the existing categorisation of Mattessich & Monsey (1992) to determine if their own categorisation had similarities or differences. The participants of the workshop reflected that having seen the model presented by Mattessich & Monsey (1992) it may be a more appropriate starting point. The outcomes of the workshop attendees categorisation were a mixture of the categories and the sub-categories. They suggested the categorisation mapping as follows:

- Teamwork identified by the participants was perceived to be analogous with membership characteristics in Mattessich & Monsey due to a focus on cooperation and participation.

- Distributed solutions identified by the participants was perceived to be analogous with resources due to considerations of how human requirements interacting with the objective of the collaboration.
- Tools identified by the participants was perceived to be analogous with resources also due to the focus on technical aspects of the availability of appropriate technologies.
- Time management identified by the participants was also perceived to be analogous with resources due to differences in time zones and ensuring the right team members are available.
- Project management identified by the participants was perceived to be analogous with process and structure related to time management and coordination, and,
- Cultural identified by the participants was perceived to be analogous with the collaborative environment due to the requirements identified of awareness, skills and contextual aspects.

An annotated image of the outcomes of the workshop is included as Appendix 6. The annotations represent the categorisations as they relate to Mattessich & Monsey (1992).

The participants further reflected that the category of *purpose* was more focused on the outcomes of the work rather than the design activity itself, and perhaps the requirements were self-fulfilling. All other categories were clear and justified, however, purpose was questioned by several participants. Further analysis was required on this category.

5.1.4 ICED17

The second workshop took place during the ICED17 conference, which focussed on the context of engineering design education. 22 workshop participants were split into three groups of seven or eight people. All who attended had experience teaching in a collaborative educational environment using technology.

Workshop participants were asked to discuss factors that contribute towards collaborative design success and failure in design education. Each group conducted a brainstorm to identify challenges, and then were asked to cluster the challenges. Both the group brainstorm and the categorisation was conducted in individual groups with 20 minutes to discuss the challenges and 20 minutes to categorise the challenges. The group were supplied with sticky notes, pens and paper to facilitate a group brainstorming session and categorisation task. Photographs were taken to record the knowledge creation.

An annotated image of the outcomes of the workshop is included as Appendix 7. The annotations represent the categorisations created by the participants as they relate to Mattessich & Monsey (1992).

Each team created their own set of factors as they emerged within their teams and categorisation. The factors were compared to the 18 sub-categories detailed earlier in this chapter.

During this activity, participants created two categories of c*ommunication* and *sharing of data*. The challenges addressed within these two categories were analysed and determined to be indistinguishable from those within the *technological factors* sub-category (18).

Following the workshop, it was decided that these two sub-categories would replace sub-category 18, making a total of 19 sub-categories. The author re-categorised the requirements assigned to the sub-category of technological factors that would be redistributed into the two sub-categories of communication and sharing of data.

5.1.5 DESIGN 2018

The third workshop was conducted at the DESIGN conference in 2018, where the focus was on collaborative design success and failure. Where the E&PDE 2016 and ICED 2017 workshops focused on an educational environment, the DESIGN 2018 workshop invited representatives with an interest in collaboration in education, academia and industry. The purpose of conducting this workshop was to identify if any requirements were missing from the list of 220 and to confirm the categorisation.

Participants were invited to define the causes of success and failure of collaborative design using Ishikawa diagrams. Ishikawa diagrams are used to represent the causes and in this workshop, the aim was to identify the causes of success or failures in collaborative design. As a structured approach, the use of Ishikawa diagrams to represent the causes aimed to explore the knowledge to a greater depth.

A diagram of the collated outcomes of the workshop is included as Appendix 8. 84 success and failure factors were identified across four categories. Three of the success and failure factors were not categorised into the four categories and included as ‘other’. The four categories identified by participants was team membership, planning, management and communication.

Considering the categorisation by Mattessich & Monsey (1992); team membership is related to membership characteristics, communication is represented as communication, planning was related to coordination which is a sub-category of process and structure, and management developed into a catch all for issues related to cooperation, trust, commonality which are further requirements under membership characteristics.

To give an example of the success and failure factors identified, 15 factors were identified and categorised as communication. These are listed as follows with an identification of how they relate to the 220 requirements of CSCD. Lack of communication (Support communication - Bittner & Leimeister (2013)), Socialisation (Allow for Serendipitous Communication - Borsato et al. (2015)), Lack of communication between all parties (Support human to human connections - Rapanta et al. (2013)), Different languages (Overcome language barriers - Rapanta et al. (2013)), Team awareness (Be made awareness of other team member’s actions - French et al. (2016)), Means to communicate - as it relates to decision making (Support efficient decision making - Shen et al. (2015)), Lack of understanding - as it relates to multidisciplinary (Support the understanding of information - Xie et al. (2010)), Clear and open channels (Communication Channels - Horváth (2012)), Different disciplines speak different languages (Overcome language barriers - Rapanta et al. (2013)), Lack of understanding - as it relates to culture (Share a global view in the aid of a shared understanding - Antunes et al. (2011)), Tacit knowledge sharing (Avoid ambiguous misunderstandings - Luck (2013)), Exchange of information (Encourage knowledge sharing - Rapanta et al. (2013)), Common language - as it relates to context specific language (Support the understanding of information - Xie et al. (2010)), Common goal (Support co-construction activities - Rapanta et al. (2013)); and, Good communication (Support communication - Bittner & Leimeister (2013)).

Following the workshop and upon analysing the outcomes, no new requirements or categories were identified. Although it cannot be confirmed that the list of 220 requirements and the categorisation is definitive, using participants' knowledge in the three workshops from across the research field gives confidence in confirming the robustness of the research.

It is important to mention that some requirements from the literature were not identified by experts during the workshops. One of these requirements, notably, was the lack of an intellectual property category, particularly as businesses require provisions to ensure work is protected. This category was not included due to the nature of the work focusing on student engineering design teams, or design within an educational environment. Work within an education environment tends to be used for assessment rather than towards a viable product, which this category usually does not apply. If the evaluation and selection method were to be developed for an industrial setting, this is one of the changes to the requirements of CSCD that would need to be considered.

5.1.6 Summary of the workshop outcomes

From the workshops, the 220 requirements were categorised. Originating from established models and established literature there were very few changes in the process of verifying the list of requirements and the categorisation. Each category and subcategory are described as follows:

Table 5-1: Description of the high-level categories (Brisco, R. I. Whitfield, et al. 2019)

Category	Description
Communication	The methods for communication and data transfer including images, text, video, audio etc. The methods that enable stakeholder response and social communication to build professional relationships.
Environment	Allowing all who require and are permitted, access to relevant information.
Resources	Ensuring teams members and work is managed to support the design process with the required skills and knowledge. Ensuring captured knowledge are effectively managed, and team members are best informed.
Membership characteristics	Access to team members' knowledge to share common experiences, values, and knowledge to support understanding between team members. Supporting a shared understanding of the project and design activities for all team members involved. The encouraging motivation for a project and the building of trust between team members.
Process and structure	Implementing systematic methods for capturing knowledge and inclusive procedures and methods for decision making.

Communication channels: refer to the ways in which a team can communicate and how they can be supported through technology use. The three sub-categories identified in the literature represent the requirements of engineering design teamwork are:

- Artefacts, the use of digital representations of physical objects and digital work;
- Feedback, on previous work to influence and future development; and,
- Social, including networking to reduce interpersonal barriers.

The **collaborative environment** refers to how collaboration is supported within an organisation, team or group. The two sub-categories identified in the literature represent the requirements of engineering design teamwork are:

- Access to information, how and where the information can be accessed for transparency and ease of use; and,
- Corporate structure, for a collaborative environment within the organisation's culture.

Process and structure are put in place to ensure systematic practices and minimise loss of data. The three sub-categories identified in the literature represent the requirements of engineering design teamwork are:

- Decision making, the ability to share opinions and make informed decisions;
- Knowledge capture, techniques and technologies to create comprehensive data stores; and,
- Productivity, to support readiness with the right skills at the right time.

The **team member characteristics** of a design team have influence over ensuring the right team members are involved with the project. The five sub-categories identified in the literature represent the requirements of engineering design teamwork are:

- Commonality (reducing barriers), consideration of differences in language, culture, social and time zones;
- Motivation, of critical team members to ensure sustained interest in a project;
- Shared understanding, of the problems, concepts and techniques;
- Cooperation, awareness of work and contribution towards co-construction activities; and,
- Trust, of the quality and completeness of the work of others.

Resource management refers to knowledge and skill assignments towards a common goal. The five sub-categories identified in the literature represent the requirements of engineering design teamwork are:

- Competency, ensuring the best team member completes the appropriate work;
- Coordination, of work and team members time efficiently;
- Innovation, promoting techniques for creativity and exploration;
- Knowledge management, of all stakeholders and awareness of the whole life span of the product;

- Communication, between team members as a resource and the nature of this communication towards supporting understanding and responsiveness; and,
- The sharing of data, the nature of the sharing and the technological features that support the method of sharing.

Following the final workshop, the 220 requirements identified from the CSCD literature were aligned to each sub-category. The full list of categories, sub-categories, requirements of CSCD and the source of each requirement is included as Appendix 9 and at doi.org/10.15129/a80174b4-1e48-4472-9fc2-e99738de523a.

5.2 Creation of CSCD requirements statements

Following the verification of the 220 requirements of CSCD by the experts and verification of the categories. There was a necessity to simplify the discussion of the requirements of CSCD. If a design team were to come together to discuss the 220 requirements, this would take a significant amount of time. As the requirements can and have been categorised there was an inquiry to determine if the requirements could be simplified.

Some of the requirements could be combined and eliminated to reduce the number of requirements e.g. Hirlehei & Hunger (2011) stated the requirement to *have a cultural awareness for distributed team members,* Rapanta et al. (2013) stated the requirement to *overcome cultural barriers;* and, Wangsa et al. (2011) stated the requirement to *have an awareness for cultural differences*. Perhaps these three requirements could be combined into one. However, the number of requirements that this approach would be applicable for was rather insignificant, reducing the 220 requirements to 178 requirements. This approach was not chosen as a more significant reduction in the discussion of requirements was required.

As sub-categories were created, there was an investigation if the 19 sub-categories could represent all 220 requirements as short statements. All requirements belonging to a sub-category would have to be represented. This established an inquiry to create CSCD requirement statements.

The purpose of creating the requirements statement was to make the information on the requirements easy to understand and easy to discuss within a team, to be used as a basis to support the evaluation and selection of technology for CSCD. By discussing 19 statements the time and focus to discuss CSCD would presume to be reduced.

Requirements statements for each sub-category were created and are detailed below with reference to the literature which supported their creation.

5.2.1 Communication

There were three main requirements identified for effective and efficient communication within CSCD. These related to: the use of artefacts to mediate communication; feedback between team members; and, in encouraging social aspects.

Artefacts are used within CSCD systems as a representation of the discussion or the product itself. These are typically image files that are integrated into the team's online design space. However, other file formats such as video or audio may also be applicable to represent an artefact (Vyas, Nijholt, and van der Veer 2010). Artefacts can help during ideation as they provide an electronic reference to stimulate conversation (Gopsill, Mcalpine, and Hicks 2013) and when used in addition to text-based ideation, they ensure a shared understanding (Herrmann, Nolte, and Prilla 2012). However, the artefact mediated communication must allow for a response with high-quality representations of the discussion topic (Vyas, Veer, and Nijholt 2012; Gopsill, Mcalpine, and Hicks 2013).

The CSCD requirements statement created that related to the artefacts sub-category was:

CSCD technology allows for artefact-mediated communication that are high-quality digital representations of physical work and ideas. These elaborate on text-based communication in the design space.

Feedback is required throughout the design process (Fruchter and Courtier 2010) as well as in manufacturing, assembly (Shen, Barthès, and Luo 2015) and through to operation after the launch of a product (Zheng and Feng 2012). In order to support the collaborative process, feedback requires the design team to define a response and add a comment to a previous conversation (Gopsill, Mcalpine, and Hicks 2013). In doing so, this will allow team members to share their views and progress the development of the product using CSCD tools.

The CSCD requirements statement created that related to the feedback sub-category was:

CSCD technology allows for feedback from stakeholders to past communication on concepts that supports reflection.

Social Aspects are important in CSCD both during human to human interactions and human to computer interactions (Wangsa, Uden, and Mills 2011; Rapanta et al. 2013). Social flexibility within the team will ensure that teams can adapt to the challenges of the project (Vyas, Veer, and Nijholt 2012). In order to ensure this, team members must overcome interpersonal barriers through extensive team familiarity, and this is reliant on the individual personalities of the team members (Cho and Cho 2014; Bittner and Leimeister 2013; Xie et al. 2010). This can be enabled through encouraging informal information sharing to enabling serendipitous communications (Borsato and Peruzzini 2015). Information flow is closely linked to the synergy of a team (Antunes et al. 2011) that can be encouraged through networking (Borsato and Peruzzini 2015) and knowledge sharing (Rapanta et al. 2013). Technologies that support CSCD must adapt to the social needs of the designer to support effective and efficient communication (Vyas, Nijholt, and van der Veer 2010).

The CSCD requirements statement created that related to the social communication sub-category was:

CSCD technology allows for social communication that encourages team synergy, knowledge sharing and serendipitous communication by supporting networking and building interpersonal skills.

5.2.2 Collaborative environment

The collaborative environment that is created for team members must offer certain freedoms. There are many boundaries that exist to restrict access to information (Wangsa, Uden, and Mills 2011). When team members are restricted to access certain information, that they require, it is not in the best interest of the project (Pavkovic et al. 2013). Team members must be encouraged to collaborate with whoever is required, both inside (Iacob and Damiani 2011) and outside the design team (Gopsill, Mcalpine, and Hicks 2013). Also, they must have access to view and edit documents in order to complete tasks and contribute to the team goals effectively.

The CSCD requirements statement created that related to the access to information sub-category was:

CSCD technology enables team members to overcome boundaries of access to easily view and edit files freely.

In many cases, the corporate structure is a defining factor in encouraging a collaborative environment within the organisation's culture (Bittner and Leimeister 2013). If a company has a history of collaboration, then it is very likely that collaboration will continue to be supported (Wangsa, Uden, and Mills 2011). However, to ensure this is the case, there must be support for team members. Procedures must be standardised across a company and globally (Shen, Barthès, and Luo 2015) to ensure predictability (Rapanta et al. 2013). Groupware is often used in larger enterprise companies to support CSCD, however, to be fully capable, they must support small negotiation cycles between team members (Rapanta et al. 2013). Also, adequate training must be given on the use of groupware systems (Rapanta et al. 2013). There must be clear roles of hierarchy to ensure team members understand their own and others’ roles and responsibilities (Bittner and Leimeister 2013; Pavkovic et al. 2013) and although freedom is vital for innovative practices, there must be some level of control from managers over the direction of the exploration (Cho and Cho 2014). However, this will only be achieved if the company can effectively implement procedures to encourage collaborative practices in the use of CSCD tools (Xie et al. 2010).

The CSCD requirements statement created that related to the corporate structure sub-category was:

CSCD technology can easily integrate with company structure through the implementation of standardised procedures and policies to ensure clear roles and responsibilities, reduce the sense of lack of control and optimised team negotiation cycles.

5.2.3 Process and structure

Process and structure play an essential role to ensure organisation and consistency. The literature search identified the areas of decision making, knowledge capture and productivity as three areas of process and structure that are important to CSCD.

Decision making is essential for design, and this process must remain as efficient as possible (Shen, Barthès, and Luo 2015). There is a need for an improved decision-making (Kosmadoudi et al. 2013) process to allow for more significant opportunities for a team member to share their opinions (Cho and Cho 2014) and in negotiation (Cho and Cho 2014; Fruchter and Courtier 2010). Specifically, it has been identified that CSCD tools are required to allow for ‘ranking functionality’ to improve support for decision making (Iacob and Damiani 2011).

The CSCD requirements statement created that related to the decision making sub-category was:

CSCD technology supports decision making through increased opportunities to express opinions, develop negotiation skills and concept ranking functionality.

Process and structure can easily breakdown if it is not done uniformly across the design process. All aspects of the conversation must be documented including: capturing meeting information (Gericke, Gumienny, and Meinel 2010), documenting decision making (Hansen and Dalsgaard 2012); and, ensuring the capture of design work in the form of high-quality artefacts (Gopsill, Mcalpine, and Hicks 2013). This can be supported by allowing tools to capture the focus of the conversation (Gopsill, Mcalpine, and Hicks 2013) and asking closed questions that can be quickly recorded (Fruchter and Courtier 2010). It is essential that technologies that support CSCD offer the ability to annotate documents (Iacob and Damiani 2011), add text-based descriptions to image audio and video files for easy searching (Gopsill, Mcalpine, and Hicks 2013) and allow for artefact mediated interactions such as the ability to easily record modifications to the artefact (Vyas, Veer, and Nijholt 2012).

The CSCD requirements statement created that related to the knowledge capture sub-category was:

CSCD technology supports knowledge capture through the recording of information, decisions and artefacts to document the design process and decision making.

When considering the process and the structure of CSCD teams, it is vital to ensure the teamwork is productive (Cho and Cho 2014). A multitude of factors influences productivity. Barriers include collaboration and technology readiness (Hirlehei and Hunger 2011), quality of the outputs (Bittner and Leimeister 2013), logistics (Xie et al. 2010) and team member factors such as group member satisfaction (Bittner and Leimeister 2013). Increased productivity can have significant effects such as: provoking reflection on design work (Hansen and Dalsgaard 2012), catching mistakes through collaboration (French et al. 2016), increased speed (French et al. 2016), thoroughly developed ideas (Cho and Cho 2014) and reduced rework time and rework loops (French et al. 2016; Bittner and Leimeister 2013; Herrmann, Nolte, and Prilla 2012). When considering productivity in a CSCD context, we must consider how teams communicate. Responses must be limited to ensure efficiency (Gopsill, Mcalpine, and Hicks 2013; Cho and Cho 2014). The conversations must be objective orientated, and technologies must support this (Wangsa, Uden, and Mills 2011). The team must be organised to ensure the most competent team member is completing the work (Jinghua, Liyi, and Hongxiang 2014) and that this work should be coupled together for the benefit of the team as a whole (Hirlehei and Hunger 2011). Also, the ability to predict team member behaviour would assist in organisation and productivity planning. Strategies have been suggested to encourage productivity in CSCD teams, such as single-tasking (van Dijk and van der Lugt 2013) and the re-use of data (Gericke, Gumienny, and Meinel 2010).

The CSCD requirements statement created that related to the productivity sub-category was:

CSCD technology allows for greater productivity through fast objective focused communication, organisation of work, reflection on completed work and a greater quantity of output to promote collaboration readiness and reduced rework time.

With the creation of the 19 requirements statements, there was a need to further consult experts to determine whether the characterisation of the requirements as statements could be considered to be accurate.

5.2.4 Resource management

Resources refer to the physical resources available to the team, such as, people and physical/digital space, as well as financial resources. competency, coordination, innovation, knowledge management and technology are the five requirements of CSCD resources.

Team member competency is essential to ensure effective and efficient CSCD. This relies on the individual team members skills as well as the diversity of skills available throughout the team (Bittner and Leimeister 2013). More capable employees as part of a team (Cho and Cho 2014) and the experience of a team with each other (Hirlehei and Hunger 2011) also play a part in the competency of the work. Communication skills are crucial in supporting team member competency, and CSCD tools need to support enhanced communication skills (Cho and Cho 2014) as well as the completeness of a communication (Xie et al. 2010). This can be negatively affected by information underload (Xie et al. 2010), where team members are not aware of the resources available. Specifically, CSCD tools must include functionality to mark conversations as concluded or complete (Gopsill, Mcalpine, and Hicks 2013).

The CSCD requirements statement created that related to the competency sub-category was:

CSCD technology allows for greater competency through increased accessibility of team skills and experience, reduction of unnecessary information and completeness of messages.

It is important for CSCD that teams are well-coordinated (Borsato and Peruzzini 2015; Bittner and Leimeister 2013; Xie et al. 2010). Lack of coordination can cause issues such as the organisation of meetings (Benolken, Wewior, and Lang 2010), scheduling problems (Fruchter and Courtier 2010) and distribution of work (Jinghua, Liyi, and Hongxiang 2014). This can be addressed through the use of gatekeepers who have the role to coordinate the communication and put people in touch with each other and resources (Xie et al. 2010). However, issues such as team members’ timeliness can never be solved through greater coordination (Xie et al. 2010). CSCD tools must offer a private space for teams to work in (Iacob and Damiani 2011). Also, teams need organisation functionality, such as, the ability to group communications and align the communication to a specific purpose (Gopsill, Mcalpine, and Hicks 2013). Team members need the ability to handle resources at their own will without relying on others (Iacob and Damiani 2011); there is a place for smart support of the process (Horváth 2012). Teams need a greater perspective of the entire design process with the ability to check an overview of the task and the necessary jobs (Pavkovic et al. 2013) this will assist with the issue that problems and solutions do not tend to develop at a similar rate (Rapanta et al. 2013). This might come in the form of a hierarchical structure of the activity (Wangsa, Uden, and Mills 2011) or through aligning the efforts of the team (Hansen and Dalsgaard 2012).

The CSCD requirements statement created that related to the coordination sub-category was:

CSCD technology supports coordination through a shared space for the organisation of work and communication, easy mechanisms for scheduling meetings and to support the even distribution of work.

It is essential to support innovation and innovative thinking within the management of resources (Bittner and Leimeister 2013; Vyas, Nijholt, and van der Veer 2010). Creativity and exploration need to be supported by CSCD tools for the benefit of the output (Vyas et al. 2010; Vyas, Veer, and Nijholt 2012; Fruchter and Courtier 2010). Tools that support easy switching between topics (Herrmann, Nolte, and Prilla 2012), problem-solving (Fruchter and Courtier 2010), and the rapid transformation of ideas into concepts (Hansen and Dalsgaard 2012) are ideal for this task. If supported correctly through resource management, this can lead to more creative outputs (Cho and Cho 2014) and better quality of outputs (Bittner and Leimeister 2013).

The CSCD requirements statement created that related to the innovation sub-category was:

CSCD technology encourages innovative thinking through agile systems to support exploration, creativity and quality of outputs.

Knowledge management is an essential practice in CSCD. It is crucial to be able to manage the communication of knowledge, and CSCD tools must support the ability to categorise, organise and reference previous communications (Gopsill, Mcalpine, and Hicks 2013). In addition, it is essential to support easy linking to specific communication (Gopsill, Mcalpine, and Hicks 2013), much like a social media approach that uses tagging to make team members aware (Iacob and Damiani 2011), but also in future technologies to seek new strategies of efficient communication (Shen, Barthès, and Luo 2015). The use of knowledge management practices presents the opportunity for information mining and elicitation (Horváth 2012). This can be supported by automation of tasks (Pavkovic et al. 2013) and intelligent data management (Horváth 2012). Information overload can hinder the project's progress if knowledge management practices are not implemented well (Xie et al. 2010). This can be addressed by using a global view to allow team members with greater information about other team members work (Antunes et al. 2011).

The CSCD requirements statement created that related to the knowledge management sub-category was:

CSCD technology supports knowledge management through the organisation of information and communication, the ability to search and retrieve knowledge easily, and autonomy in the distribution of knowledge.

Technology represents the infrastructure that brings CSCD together. CSCD tools must inherently support the collaborative design process (Pavkovic et al. 2013; Borsato and Peruzzini 2015). Unfortunately, employees are not always aware of the functionality of their tools and the benefits this can bring (Rapanta et al. 2013). Barriers exist with modern Technologies that support CSCD. Incompatibility between file formats and the software itself can cause issues for teamwork (Rapanta et al. 2013), or when the software itself fails to operate the way it has been designed to (Pavkovic et al. 2013; Fruchter and Courtier 2010; Antunes et al. 2011). Teams must have access to appropriate tools and technologies to support their work (Liu and Lou 2014). These technologies might include communication support (Bittner and Leimeister 2013) such as a messenger (Benolken, Wewior, and Lang 2010) or integrated chat within technologies such as 3D CAD (Iacob and Damiani 2011), data storage solutions (Gericke, Gumienny, and Meinel 2010) and audio and video conference tools (Benolken, Wewior, and Lang 2010). These tools must offer teams the ability to communicate using multiple communication channels (Horváth 2012; Vyas et al. 2010) with multi-threading capabilities and the ability to respond to multiple threads with a single response (Gopsill, Mcalpine, and Hicks 2013). Also, the tools must offer the ability to share models and documents (Horváth 2012) synchronously (Zheng and Feng 2012) and have the functionality to track this work and view versions of past work (Iacob and Damiani 2011).

The CSCD requirements statement created that related to the communication sub-category was:

CSCD technology supports communication through synchronous multi-threaded and multi-channel software for prompt discussion in a way that supports the context of the message.

When teams are collaborating, they need the ability to work with live documents (Herrmann, Nolte, and Prilla 2012) that allows everyone to take part at once (Iacob and Damiani 2011). However, this co-creation requires smart support to ensure the technology functions as expected by the user (Horváth 2012). This smart support is also required for virtual presence tools to ensure teams can communicate when required but are not distracted by the technology (Horváth 2012). It is essential that, where possible, these technologies are integrated, such as with sophisticated groupware or can easily link with each other, such as social media integration (Shen, Barthès, and Luo 2015). Also, where possible, technology should integrate with the ‘offline space’ that has excellent benefits for awareness between team members (Vyas, Nijholt, and van der Veer 2010; Vyas, Veer, and Nijholt 2012). Technologies that support CSCD need to be adapted to the team members need. Tools such as CAD must support third party program integration, such as video conference tools, to encourage collaboration (Horváth 2012). The interface that the team member uses to interact with the system must be adaptive for their needs (Horváth 2012) and consistent with the user's expectations (Iacob and Damiani 2011). The information must be easy to access (Zheng and Feng 2012) for team members and easy to share (Shen, Barthès, and Luo 2015; French et al. 2016). Also, team members need to push information to others (Gopsill, Mcalpine, and Hicks 2013). Devices that team members use must support the functionality of the tool, and this requires the devices themselves to have some flexibility in their functionality (Iacob and Damiani 2011). Importantly for design, technology must support the ability to propose design change and support this process through to the implementation of this change (Hansen and Dalsgaard 2012).

The CSCD requirements statement created that related to the sharing of data sub-category was:

CSCD technology reduces complexity in sharing data through integration with data storage systems, reduced file compatibility issues and synchronous live document working with automated tracking and versioning to enable co-creation of documents.

5.2.5 Membership characteristics

The success of teamwork is influenced by many characteristics of the team and the individuals within the team. The literature found five aspects that are essential to consider within the CSCD system. These include; commonality on aspects such as culture, language and time zone, the motivation of team members, ensuring a shared understanding of the state of the product and goals, team Cooperation and trust.

Commonality is vital to collaborative design as it ensures a common language and instils a sense of belonging within teams. Differences in communities and cultures can have adverse effects on a team member’s ability to relate with others and clearly explain their ideas (Hirlehei and Hunger 2011; Rapanta et al. 2013; Wangsa, Uden, and Mills 2011). Similarly, language barriers can harm the group’s ability to communicate (Rapanta et al. 2013). These issues are amplified when team members do not share a physical space (Wangsa, Uden, and Mills 2011; Bittner and Leimeister 2013) or are geographically separated (Hirlehei and Hunger 2011).

The CSCD requirements statement created that related to the commonality sub-category was:

CSCD technology reduces the barriers of physical proximity, cultural and language barriers, and time zones and enables greater awareness of community and environmental issues.

Motivating a team can be difficult when team members are unwilling to participate in collaborative practices (Rapanta et al. 2013) when team morale is low (Bittner and Leimeister 2013), or they are simply not engaged with the work (van Dijk and van der Lugt 2013). It is important to encourage team members through incentives for high quality timely work (Bittner and Leimeister 2013) or through strategies such as gamification (Herrmann, Nolte, and Prilla 2012). Long sustained interest in a project is challenging to achieve (Kosmadoudi et al. 2013). However, this can be supported by ensuring resolution of design decisions is frequent (Fruchter and Courtier 2010), and it has been shown that increased information flow can be achieved through positive reinforcement (Antunes et al. 2011).

The CSCD requirements statement created that related to the motivation sub-category was:

CSCD technology encourages motivation through social incentivisation, positive reinforcement, gamification and encouraging good morale to ensure long sustained interest in the project and to overcome barriers of conflict.

Ensuring that team members have a shared understanding is crucial in a collaborative setting. This relies on several factors that influence the conversation. Teams must be able to discuss problems within an everyday context (Hirlehei and Hunger 2011; Wangsa, Uden, and Mills 2011) but this requirement can be affected by the distance between team members and their relationship (Antunes et al. 2011). How the information is communicated and understood can affect teamwork (Xie et al. 2010). The presentation of the information affects the ability to understand the clarity of what is said (Fruchter and Courtier 2010). Miscommunication from the sender (Cho and Cho 2014) or misunderstandings by the receiver (Luck 2013) can affect the ambiguity of the shared understanding or can create false information altogether. Explanation, clarification (Fruchter and Courtier 2010), and articulation (Liu and Lou 2014) have a part to play when considering the understanding of information that can create a common ground to work from (Fruchter and Courtier 2010). This requires team members to have the ability to define the purpose of the conversation (Gopsill, Mcalpine, and Hicks 2013) both socially in conversation, and through the use of the technologies. Team members need to have a 'global view' of the situation that a shared understanding can provide (Antunes et al. 2011) and can be achieved through the use of pervasive communication systems (Borsato and Peruzzini 2015).

The CSCD requirements statement created that related to the shared understanding sub-category was:

CSCD technology encourages a shared understanding by defining and framing the conversation in a shared context through shared global pervasive environments that make it easy to understand information, clarify meaning and reduce miscommunications

It is essential for teams to have good Cooperation to accomplish tasks (Vyas et al. 2010). This is especially true in a distributed setting (Borsato and Peruzzini 2015) and for design, as a co-construction activity (Rapanta et al. 2013). To support Cooperation, team members must anticipate the needs of their other team members (Pavkovic et al. 2013). This can be achieved through an awareness of team members work (Borsato and Peruzzini 2015; Herrmann, Nolte, and Prilla 2012; Iacob and Damiani 2011) and of team member activities (French et al. 2016; Liu and Lou 2014). Awareness can be supported through shared visualisation systems (Benolken, Wewior, and Lang 2010), mediated coordination, also known as direct supervision, from a manager (Shen, Barthès, and Luo 2015) and organisation of regular project reviews (Pavkovic et al. 2013). Unfortunately, it is difficult in a collocated and a distributed setting to ensure equal participation of all team members (Cho and Cho 2014) but, this can be assisted by modern methods of communication such as a constant connection (French et al. 2016). Pervasive communication offers more opportunities for peer learning and training, and for greater retention of this learning (Dym et al. [6] in French et al. (2014)). Poor communication, in contrast, has the capability to hinder a team's ability to conduct tasks (Xie et al. 2010) that can be devastating for the outcomes of the project.

The CSCD requirements statement created that related to the cooperation sub-category was:

CSCD technology encourages Cooperation by enabling a constant connection and increased awareness to encourage equal participation, the anticipation of project needs, supporting design activities and opportunities for peer learning.

Increased trust between team members is required to support collaborative design practice (Pavkovic et al. 2013; Rapanta et al. 2013). Trust can be negatively affected by team member's communication, particularly when the information is inaccurate, distorted or conflicting with the member's point of view (Xie et al. 2010). This can cause conflict between team members (Wangsa, Uden, and Mills 2011). However, it is essential to note that although a constant level of trust is beneficial, it is not required at all stages of the design process (French et al. 2016).

The CSCD requirements statement created that related to the trust sub-category was:

CSCD technology encourages trust to support conflict resolution through increased accuracy and clarity of communication between team members.

5.3 Evaluation of CSCD requirements statements

The successful creation of CSCD requirements statements produced a usable list of requirements for the purposes of evaluating and selecting technology against these requirements. However, the statements were created by the author and lacked validation. If the statements inaccurately represented the CSCD requirements this would have an impact on the entire evaluation and selection method.

To validate the CSCD requirements statements a questionnaire was created and experts in CSCD were asked to contribute to its completion. From the results, the CSCD statements were changed to reflect comments by the experts in CSCD and the CSCD requirements statements were ranked in order of importance for engineering design teams. This chapter details the consideration for the creation of the questionnaire and the results.

5.3.1 Questionnaire design

The questionnaire was created to collect the opinions of experts in CSCD on the CSCD requirements statements. The questionnaire began with an introduction to the study and its scope, explaining why the data was being collected i.e. to validate the CSCD statements for the purpose of evaluating and selecting technologies for CSCD. A definition of CSCD was provided to contextualise the nature of the study as follows:

Computer-Supported Collaborative Design (CSCD) is the area of research concerned with investigating how technology can be used in the designing of a product through collaboration among multidisciplinary product designers associated with the entire product life cycle.

The definition of CSCD was included on each page of the questionnaire to allow participants to remind themselves of the scope of the study as required.

Experts were asked as part of the page detailing the purpose of the study to self-assess their level of expertise in CSCD and the necessary data collection privacy information.

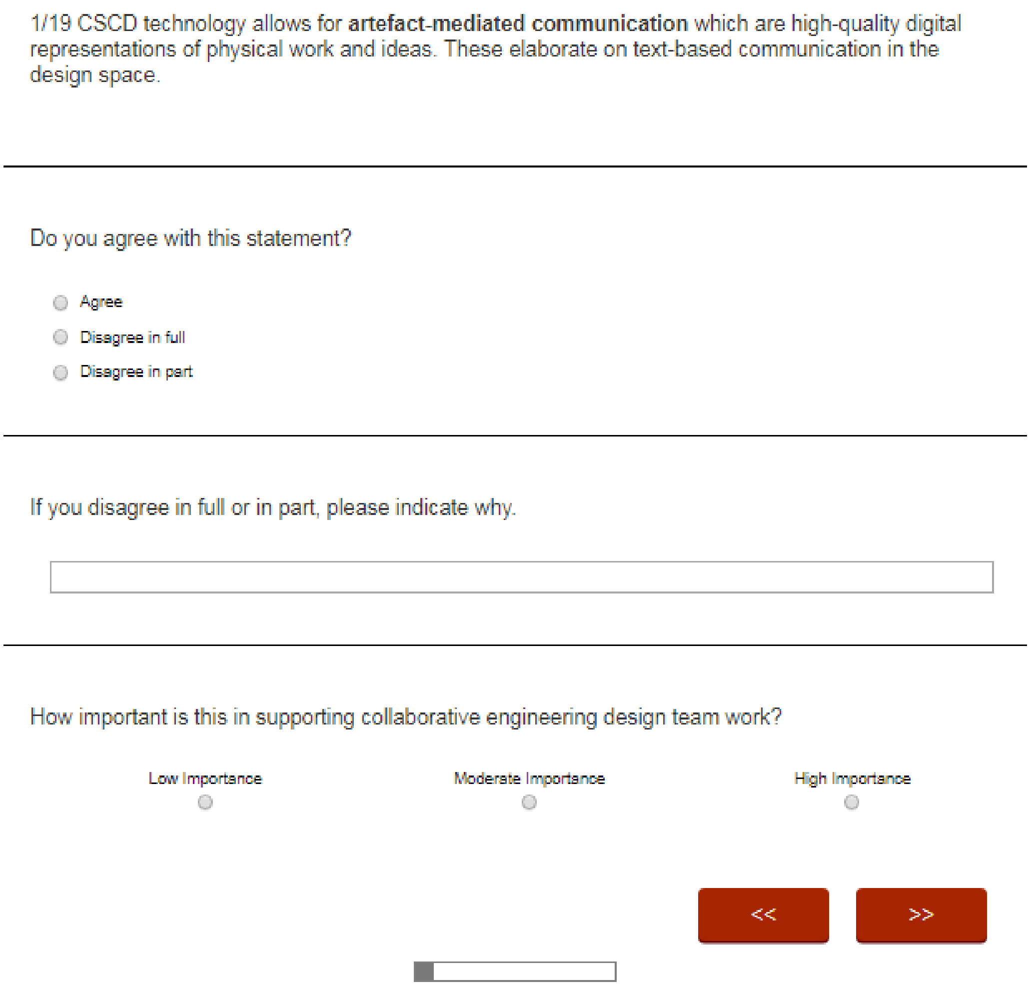
On each page of the questionnaire, one of the 19 CSCD requirements statements was provided, and three questions were selected to collect information from the experts. These questions were

> Q1. Do you agree with this statement? (Checkbox provided with three responses: Agree, Disagree in full. Disagree in part);

Q2. If you disagree in full or in part, please indicate why. (Text box provided for response); and,

Q3. How important is this in supporting collaborative engineering design teamwork? (scale provided with three responses: low importance, moderate importance, and high importance).

The first page of the questionnaire, including the first CSCD requirements statement on artefact-mediated communication. Figure 5-3 is a screenshot of the first page of the questionnaire. The questionnaire was used to elicit responses from academic experts to test the level of agreement with each of the 19 requirements statements. This feedback from experts was used to redevelop the CSCD requirements statements when required and to rank the statements in order of importance.


1/19 CSCD technology allows for **artefact-mediated communication** which are high-quality digital representations of physical work and ideas. These elaborate on text-based communication in the design space.

Do you agree with this statement?

- Agree
- Disagree in full
- Disagree in part

If you disagree in full or in part, please indicate why.

How important is this in supporting collaborative engineering design team work?

Low Importance | Moderate Importance | High Importance

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Figure 5-3: A sample page of the questionnaire displaying the first of 19 CSCD statements

Following the 19 questions on the statements, a final text box was provided to collect any additional feedback that the participants may wish to contribute on the study as a whole.

The questionnaire was delivered to experts using an invitation by email. The experts were selected because of their expertise in facilitating CSCD within an academic or educational environment, or who had published on the topic as identified using the systematic literature review. A list was created by the author from details provided at workshops (when participants checked a box to agree to be contacted about research in the future), by the corresponding author's email address listed on published literature, or through publicly listed information on university profile pages and profiles available to members of The Design Society.

5.3.2 Questionnaire responses

87 participants were invited to take part in the research, and 25 responded. Individual responses to the questionnaire are available at: doi.org/10.15129/ed3431c1-aa67-47a5-ac7e-ae5a6c3ba8f4.

One respondent indicated themselves as having a low familiarity to the field of CSCD based upon the CSCD statement provided. This response was removed from the data analysis. The identities of these participants have been omitted from the main body of this work due to data privacy regulations. The remaining 24 responses were analysed as follows.

The majority of experts responses to the questionnaire across all CSCD requirements statements were either agree or disagree in part, as displayed in

Table 5-2. Very few disagreements in full were recorded which supports the general representation of the statements for requirements of CSCD.

Where disagreement in full or in part was selected, the comments were used to understand why there was disagreement and how the statement might be changed to better represent the views of the experts.

The first change that was made from comments suggested by the experts affected all of the statements. This comment was identified mainly by those who agreed in part with the statement but not entirely. Experts commented that the statements should not focus on the positive outcomes exclusively as this was misleading by the nature of the statement. Instead, they should be worded to say that CSCD *could* have these outcomes if the requirements were satisfied. The statements were worded as a potential for that CSCD could achieve, and in many cases, is not the reality. They are perhaps an ideal to be pursued. However, the requirements and statements are created from case studies from the literature on CSCD. An example of this is given as the statement for artefact-mediated communication as follows:

CSCD technology could allow for artefact-mediated communication that are high-quality digital representations of physical work and ideas. These elaborate on text-based communication in the design space.

Table 5-2: Assessment of the current CSCD statements

Statement category	Agree	Disagree in part	Disagree in full
Sharing of data	16	7	1
Shared understanding	18	5	1
Cooperation	17	6	1
Knowledge management	20	3	1
Feedback from stakeholders	16	7	1
Social communication	19	5	0
Knowledge capture	20	3	1
Communication	19	5	0
Overcome boundaries of access	13	9	2
Building of trust	13	8	3
Co-ordination	22	2	0
Artefact-mediated	14	10	1
Reduce the barriers (Commonality)	12	11	1
Decision making	17	6	1
Greater productivity	12	10	2
Innovative thinking	12	10	2
Greater competency	12	9	3
Motivation	11	12	1
Company structure	11	13	0

One prominent comment with those who disagreed with the statements was: ‘other approaches can do this also’ meaning although the statements represent some of the requirements, there could be more. For example, the statement on artefact-mediated communication mentions 'text-based communication in the design space' and the participant who disagreed with this indicated that other communication methods are available. This is true; however, the efforts to verify and validate the list of 220 requirements of CSCD were implemented to ensure the statements were as complete as possible based upon published research. It is also true that there may be new technologies or methods that support new tools in the future. This could also account for the respondent commenting on individual statements when they had not yet seen the complete list.

A general comment made was that many of the statements, although focusing on CSCD, could also be applied to cultural, human, and people-oriented challenges and not only technological ones. While it was not the intent of the study, it may also be of academic interest to analyse the 220 requirements as a human or a technological influence, as this could have implications for human-centred research or computer-supported research. This is further discussed in Chapter 6.

In the following sections the statements are changed with a notation to display the new statement. Where additions are made, these are highlighted in **bold** and where text is removed this is indicated with a ~~strikethrough~~.

5.3.2.1 Artefact-mediated communication

The statement created for artefact-mediated communication in the questionnaire was:

CSCD technology allows for artefact-mediated communication that are high-quality digital representations of physical work and ideas. These elaborate on text-based communication in the design space.

54% of participants agreed with the statement, (4%) one expert disagreed in full and 42% in part. Most experts agreed with the statement, and minor changes were considered.

Comments of those who disagree included:

- "It is missing people", was interpreted to mean that the requirement statement does not represent human factors. The statement should not and should be detached from either human or technological influences;
- "Communication is not only text-based ..." was interpreted to be referring to gesture, inflexion, and social factors which influence communication. The text based reference was removed to allow ambiguity for all types of artefact-mediated communication; and,

- "Communication and collaboration are contrasting activities. Communication does not necessarily facilitate collaboration", which is a subjective view popular in computer science literature depending on the model of collaboration employed. This was not implemented in the changes to the statement.

This statement was changed to:

*CSCD technology **can allow** for artefact-mediated communication that are high-quality digital representations of physical work and ideas. ~~These elaborate on text-based communication in the design space.~~*

The part referring to elaborating on text-based communication as artefacts can be used to elaborate on many forms of communication. When asked how important this requirement statement is for CSCD teamwork, most experts agreed that it was of high importance at 67%. 12% of experts believed it to be of low importance and 21% moderate importance.

5.3.2.2 Feedback from stakeholders

The statement created for feedback in the questionnaire was:

CSCD technology allows for feedback from stakeholders to past communication on concepts that supports reflection.

67% of participants agreed with the statement, (4%) one expert disagreed in full and 29% in part. Most experts agreed with the statement, and so minor changes were considered.

Comments of those who disagree included:

- "Feedback is only one part of NPD activities", where the expert has assumed the factors can only be applied to new product development. And so this is a misinterpretation;
- "Unfortunately, computational tool fails to communicate emotions and emotion displays are the most powerful predictors of breakthrough team innovation", suggests that emotions need to be highlighted in the statement and were added;
- "The ability of stakeholders to provide feedback strongly depends on how they are introduced to artefacts. Just showing them artefacts that they have never seen would not work", highlights that context is essential which is added; and,
- "Yes, technology allows that, but what would be achieved this context highly depends on knowledge, experience and training of stakeholders", which suggests there needs to be more to this statement in terms of resources which have been added.

In addition to the missed requirements in the statement, the ability of current technology was questioned. One expert stated: “At the moment, I do not find the technology suitable to retrieve past communication on concepts that supports reflection. Typically emails exchanged between PD stakeholders are used to retrieve past decisions made”. This highlights the ubiquity of email but its position as a substandard tool to support design communication and then collaboration. Another expert theorised: “This is not a question of technology but of 'culture'?”, however within the context of CSCD it is the view of some researchers that the technology should enable team members to overcome cultural barriers, but in many cases, they can be made worse (J. et al. 2010; Bittner & Leimeister 2013; Wangsa et al. 2011; Rapanta et al. 2013). In a final statement, an expert stated: “It may or it may not [referring to the statement]. It depends if it is for collaboration between designers or has broader capabilities”. This expert was interpreted as referring to the scope of feedback. In the statement, stakeholders are referring to ‘broader capabilities’, from suppliers to distributors, designers to shareholders and of course, the customer/user.

This statement was changed to:

CSCD technology can allow for feedback from stakeholders to support reflection on past communication and concepts dependent on the context, knowledge, experience and competency of the stakeholders.

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 75%. 8% of experts believed it to be of low importance, and 17% moderate importance.

5.3.2.3 Social communication

The statement created for social communication in the questionnaire was:

CSCD technology allows for social communication that encourages team synergy, knowledge sharing and serendipitous communication by supporting networking and building interpersonal skills.

79% of participants agreed with the statement, no experts disagreed in full and 21% in part. Most experts agreed with the statement, and so minor changes were considered.

Comments of those who disagree include:

- “If it works well and is used as intended”, highlighting a significant problem for technologies that support CSCD in terms of suitability of the technology, reflecting on the requirement for a technology evaluation and selection method for CSCD;

- "The question allows different answers with respect to the state-of-the-art or if I evaluate the potential CSCD has got...", which is true as the requirement statements can be updated based on state-of-the-art and can be applied to many different problems and contexts. However did not influence the statement; and,
- "Whilst some teams are distributed, the majority are not", which may be true as the core team may be collocated. However, they will be expected to work with stakeholders around the world on design activities and so this comment was disregarded for a more generalised statement.

Other comments were made: firstly that "Social media partially meet this requirement. I can see this when our students involved in a global design exercise engage and interact with each other. This is especially true when different cultural backgrounds are present within the team", which encourages new technologies and emerging research into this area (Gopsill 2014). Furthermore, "The most powerful predictor of collaboration success is found in the cumulative valence (+ / -) of communication between team members" that is related but has been categorised as a separate part under 'decision making', and it is believed by the author to fit best in the model as a separate category.

This statement was changed to:

CSCD technology ***can allow*** *for social communication that encourages team synergy, knowledge sharing and serendipitous communication by supporting networking and building interpersonal skills.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 71%. One expert (4%) believed it to be low importance and 25% moderate importance.

5.3.2.4 Overcome boundaries of access

The statement created for overcome boundaries of access in the questionnaire was:

CSCD technology enables team members to overcome boundaries of access to view and edit files freely easily.

54% of participants agreed with the statement, (8%) two experts disagreed in full and 38% in part. Most experts agreed with the statement, and so minor changes were considered.

Comments of those who disagree include:

- "Access as version control and edit options = yes. Access as meaning = NO", which was interpreted to be referring to an individual's ability to access potentially restricted files that may not be an option in certain industry contexts. This is incorporated by the statement;
- "Again, if it is user friendly and intuitive and team members know how to use it", that is a recurring issue of technologies that support CSCD. This is better positioned within other statements and was not included here;
- "In some cases, a user may only be able to comment on a file or add annotations to a screenshot or other lightweight version", referring to the capabilities of common technologies; and,
- "Sophisticated parametric modellers already enable this", which they may well do and they should be evaluated using criteria to determine performance as is the direction of the research towards an evaluation and selection method.

In addition, other comments were made. Firstly that "It is not as simple as it seems. Much more research is needed in this area" referring to the lack of academic research and software creator guidance in this field, but not the number of attempts and software variation available to teams. Furthermore, "This should be the case but to my (understanding) it often is not" again suggesting the requirement statement is almost an ideal that some technologies are moving towards achieving.

This statement was changed to:

CSCD technology ***can enable*** *team members to overcome boundaries of access to view and edit files when required easily.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 67%. 8% of experts believed it to be of low importance and 25% moderate importance.

5.3.2.5 Company structure

The statement created for company structure in the questionnaire was:

CSCD technology can easily integrate with company structure through the implementation of standardised procedures and policies to ensure clear roles and responsibilities, reduce the sense of lack of control and optimised team negotiation cycles.

46% of participants agreed with the statement, no experts disagreed in full and 54% in part. Most experts disagreed in part with the statement, and changes were investigated and made.

Comments of those who disagree include:

- "Depends on the company" and "it assumes that only one company is involved", that is correct - the requirement statement should reflect such to refer to agreements between companies;
- "It is difficult to anticipate what (the) company policies will be, so I do not think that CSCD technology can be 'easily' integrated in each case" and "Not always 'easily'. There may be organisational, social and technological issues to overcome. There also has to be an agreement at all levels within a company for successful integration", both statements are accurate, and the requirement statement should reflect this by adding 'can' as this is dependent on success; and,
- "Processes vary widely in industry. What company A has implemented already, maybe a vision for company B" that reflects the complication of fragmentation and so there may need to be more informal agreements that regimented guidance. Whist this is true it is not the motive of this statement.

Other, comments were made. Firstly that "CSCD as implemented today facilitates Cooperation and coordination. It undermines collaboration (agreeing to disagree)", that is neither agreeable or disagreeable but depends on the model of collaboration employed. Secondly, an expert remarked, "My experience is that should make sense for the persons using it, or it will not be integrated" referring to the ease of use of the technology that is included in technological requirements. Finally, "It is not necessarily easy to do this in practice. It is, however, highly desirable" highlighting the need for new strategies and research into the implementation of technologies that support CSCD.

This statement was changed to:

CSCD technology ***can integrate*** *with company structure through the implementation of procedures, policies* ***and agreements*** *to ensure clear roles and responsibilities, reducing the sense of lack of control and optimising team negotiation cycles.*

When asked how important this requirement statement is for CSCD teamwork, a minority of experts agreed it was of high importance at 29%. One expert (4%) believed it to be low importance and 67% moderate importance. Then, the importance of the integration of technologies that support CSCD with company structure and their ability to support structures should be investigated further.

5.3.2.6 Decision making

The statement created for decision making in the questionnaire was:

CSCD technology supports decision making through increased opportunities to express opinions, develop negotiation skills and concept ranking functionality.

71% of participants agreed with the statement, (4%) one expert disagreed in full and 25% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagree were:

- “negotiation skills are not necessarily linked to technology” which is contradictory to the research of Cho & Cho (2014; 2010).

Other comments were made such as “Decisions related to Cooperation are facilitated. Decisions related to collaboration are de-facilitated”, which was interpreted to be referring to how it is easier to cooperate with someone than to collaborate, but this is not the same as ease of decision making and is a generalisation of all cooperation and collaboration decision making which may not be true. Furthermore, one expert stated, “Yes CSCD can support decision making. It allows increased opportunities to express opinions; not so (Convinced) that it develops negotiation skills (any more) than offline experience…” which may be true, but the requirement statements do not claim CSCD to be any better than offline collaborative design.

The author reviewed the statement and changed the placement of “Increased opportunities” as concept ranking is a functionality and is not influenced by opportunities.

This statement was changed to:

CSCD technology ***can support*** *decision making through concept ranking functionality,* ***increased opportunities*** *to develop negotiation skills and express opinions.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 54%. No experts believed it to be low importance and 46% moderate importance.

5.3.2.7 Knowledge capture

The statement created for knowledge capture in the questionnaire was:

CSCD technology supports knowledge capture through the recording of information, decisions and artefacts to document the design process and decision making.

83% of participants agreed with the statement, (4%) one expert disagreed in full and 13% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "Design knowledge capture and re-use have been the core descriptor for our research for decades. Capture has gotten easier. Re-use has not gotten easier", which is a view that does not take into consideration how ease of searching can support re-use of knowledge. This will be highlighted;
- "Knowledge capture is not an easy question. Recording these elements do not imply knowledge capture", which does not consider the recording of information and decisions that contributes towards knowledge capture; and,

This statement was changed to:

CSCD technology ***can support*** *knowledge capture through the recording of information, decisions and artefacts to document the design process* ***and contribute to decision making and re-use of knowledge****.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 67%. No experts believed it to be low importance and 33% moderate importance.

5.3.2.8 Productivity

The statement created for productivity in the questionnaire was:

CSCD technology allows for higher productivity through fast objective focused communication, organisation of work, reflection on completed work and a higher quantity of output to promote collaboration readiness and reduced rework time.

50% of participants agreed with the statement, (8%) two experts disagreed in full and 42% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "In my opinion, CSCD technology must still be complemented with physical meetings", which the requirement statement does not disagree with; and,

- "CSCD technology does allow for greater productivity if work is organised well. It also allows for reflection on work carried out as it is retained. Often records are not complete or in some cases not even kept", which highlights the importance of reflection, that is prominent in the literature and the human factors in recording information. This was added to the statement.

In addition, other comments were made. An expert remarked, "It depends (on) the established rules. Communication must be regulated with mandatory meetings at specific times and then allow flexibility for continuous communication when needed". This is a relevant point of the difference between objective focused communication and continuous communication. Furthermore, "I would need convincing that a greater quantity of output is produced; that is often determined by the nature of team members and task. Greater productivity would be achieved by greater focus - so if CSCD can promote focus-on-task then I agree but that might not just be 'greater' productivity (numerically speaking), but 'greater' in terms of higher quality outputs". This is a relevant point, but a higher quality of output has been considered within other statements as it relates less to productivity.

This statement was changed to:

CSCD technology ***can allow*** *for higher productivity through fast objective focused communication, organisation of work and a higher quantity of output to promote collaboration readiness,* ***reflection*** *and reduced rework time.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 54%. No experts believed it to be low importance and 46% moderate importance.

5.3.2.9 Reduce the barriers (commonality)

The statement created for reduce the barriers in the questionnaire was:

CSCD technology reduces the barriers of physical proximity, language and time zones and enables greater awareness of culture and global issues.

50% of participants agreed with the statement, (4%) one expert disagreed in full and 46% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagree include:

- "Not true for cultural barriers" and "Cultural and language barriers continue... although physical proximity is reduced. There are still issues that must be addressed" referring to the human factors of acceptance and awareness of other cultures which should be clearer within the statement; and.

- "The potential is there, but again it depends on how it is used and the users' knowledge and Motivation" referring to the drive of individuals within a team.

In addition, other comments were made. Firstly "This is the case if done properly. If not, it can lead to even more alienation than simply having a phone call every couple of weeks". This opinion highlights the role of individuals in ensuring excellent communication but technology has a role in ensuring awareness and prompting discussion. Secondly, a respondent shared "30+ years of technology advance in CSCD has not made distributed collaboration better and the tech usage undermines human-human communication". "Better" in this context was interpreted to mean 'better than collocated collaboration' but this opinion removes itself from situations where collocated collaboration is not a possibility, or there is no necessity for collocated work such as with asynchronous work. Although CSCD may not be at the same level as face-to-face work, there have been many improvements in technologies that support CSCD from text-based communication to audio to video and now onto immersive environments. Finally, an expert shared their opinion: "Yes, CSCD technology reduces the barriers of physical proximity and supports management of time zones, however, language barriers still exist until a language common to all is used. Cultural barriers can be reduced, not so much by the technology itself but through better understanding of the cultural issues and acceptance of these. I agree CSCD enables a greater awareness of community and environment if a shared collaborative approach is adopted". This expert point on a common language can be assisted by translation software, and this is beginning to become more integrated with modern social network sites. The expert goes onto share that the issue with current technology is not its capabilities but the procedures and interaction with humans. This is a significant focus for this type of research, and there is yet to be a consensus.

This statement was changed to:

*CSCD technology **can reduce** the barriers of physical proximity, language and time zones, and enables greater awareness of culture **and the global community**.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 54%. No experts believed it to be low importance and 46% moderate importance.

5.3.2.10 Motivation

The statement created for motivation in the questionnaire was:

CSCD technology encourages motivation through social incentivisation, positive reinforcement, gamification and encouraging good morale to ensure long sustained interest in the project and to overcome barriers of conflict.

46% of participants agreed with the statement, (4%) one expert disagreed in full and 50% in part. Most experts disagreed in part with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "Agree with everything except … CSCD technology is required to overcome barriers to conflict. This is a social activity", and technology facilitates the process, overcoming barriers. The statement was kept the same; and,
- "Regarding conflicts I'm not sure whether CSCD (impact) is always positive or there are situations where it could be also negative", that is accurate and so technologies need to be managed correctly by the team members. The statement was updated based upon this.

In addition, other comments were made: "I witness that CSCD usage by distributed teams in my graduate course aggravates differences not common ground". This respondent is referring to common ground as a social issue and not as a communication issue as intended. There may be a need to clarify the difference, but other authors did understand the difference. Secondly, "When correctly managed motivation can be increased. However, if the expectations are not well managed, participants can lose motivation if they perceived their partners are not collaborating with the same intensity or quality as them". This statement is very true and their does need to be some mechanisms and motivation to encourage the project to progress. Thirdly "I would not say this has been covered extensively in the literature, but achieving a critical mass of usage is probably the most fundamental aspect for the success of any online system". This is a relevant point that the respondent is right in saying it has not made its way into CSCD research yet but is beginning to emerge in open-source design projects. The requirements discussed contribute towards achieving a critical mass, but there is no way to guarantee this. Finally, "F2F is at least a strong motivation since one cannot escape or be an observer that easily" referring to the issue of social inactivity as a mechanism to drive a project.

This statement was changed to:

CSCD technology ***can encourage*** *motivation through* ***mechanisms*** *of social incentivisation, positive reinforcement, gamification or encouraging moral decisions to ensure long sustained interest in the project* ***and if implemented correctly can help avoid conflict and support conflict resolution***.

When asked how important this requirement statement is for CSCD teamwork, a minority of experts agreed it was of high importance at 42%. 16% of experts believed it to be of low importance, and 42% moderate importance. There then needs to be a consideration if encouraging motivation of team members is an essential requirement when considering the use of technologies that support CSCD for engineering design teams.

5.3.2.11 Shared understanding

The statement created for shared understanding in the questionnaire was:

CSCD technology encourages a shared understanding by defining and framing the conversation in a shared context through a shared global pervasive environment, that makes it easy to understand information, clarify meaning and reduce miscommunications.

75% of participants agreed with the statement, (4%) one expert disagreed in full and 21% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagree include:

- "An (intensification) of communication can have a contrary effect and can even generate miscommunication..." which is an interesting point, but there is no suggestion in the requirement statement towards an "intensification of communication" as technologies that support CSCD may offer the opposite in certain contexts. It is dependent on the technology selected which highlights that a pervasive environment may not be required; and,
- "Again this is more about the artefacts and the ways they are used" that refers to the human factors in technology use.

Other comments were made that "CSDC technology rarely, if ever, accommodates cultural-institutional differences and becomes a sort of lowest common denominator". This appears to be true for student projects, and highlights a potential gap in current knowledge that may be included in the statement in the future.

This statement was changed to:

CSCD technology ***can encourage*** *a shared understanding by defining and framing the conversation in a shared context ~~through a shared global pervasive environment,~~ that makes it easy to understand information, clarify meaning and reduce miscommunications.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 71%. No experts believed it to be low importance and 29% moderate importance.

5.3.2.12 Cooperation

The statement created for cooperation in the questionnaire was:

CSCD technology encourages Cooperation by enabling a constant connection and increased awareness to encourage equal participation, the anticipation of project needs, supporting design activities and opportunities for peer learning.

71% of participants agreed with the statement, (4%) one expert disagreed in full and 25% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "constant connection? in reality, not always", which is correct, and this needs to be changed to less strong language in the statement. A constant connection related to awareness and connectivity; and.
- "equal participation does not depend on the technology use; it depends on the commitment of the (participants) and the opportunity given to participate", which does not take into consideration the role technology has in social pressure driven by increased awareness. No changes were made based upon this.

In addition, other comments were made. "CSCD strongly encourages cooperation and diminished collaboration" that is only one view driven by models of collaboration.

This statement was changed to:

CSCD technology ***can encourage*** *Cooperation by enabling ~~a constant connection and~~ increased awareness* ***and connectivity*** *to encourage equal participation, support design activities by anticipating needs and opportunities for peer learning.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 75%. One expert (4%) believed it to be low importance and 21% moderate importance.

5.3.2.13 Building of trust

The statement created for trust in the questionnaire was:

CSCD technology encourages trust to support conflict resolution through increased accuracy and clarity of communication between team members.

54% of participants agreed with the statement, (12%) three experts disagreed in full and 34% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- “I don't see CSCD technology "encouraging trust"/ I think CSCD technology facilitates the building of trust (It might be just a semantic interpretation)”, this is a valid point that should include in the requirements statement; and,
- “I would add transparency” is also valid as it is featured within the CSCD literature and is related to accuracy and clarity but has further implications.

In addition, other comments were made that “technology is not necessarily linked to trust” which is untrue according to these studies (Sarka et al. 2014; Vidovics et al. 2016; Rapanta et al. 2013). This confusion was clarified by another expert’s comments stating, “Again, yes CSCD surely helps, but I would not agree that it always increases accuracy and clarity of communication. There are many situations where these aspects of communication are influenced by many other requirements, regardless of CSCD is used or not. I would rather say that CSCD may help to speed up the clarification process”, referring to the complexities that technology can add to the problem as well as those it alleviates. Secondly, “CSCD facilitates the communication of facts but not feelings, the why behind our choices. Trust is emotion-based, not fact-based” and “The technology itself does not the guidelines and structures for communication do”. These experts are highlighting that structure is required for building trust, but informal software also has a role in sharing communication and building this. Finally, an expert shared, “Lack of social connection and bonding could take much longer to build 'trust'. It is much harder to achieve clarity in communication online than f2f”. I disagree with this expert as it might be more difficult if all information is not present or the information is presented in a difficult to understand format. Some written and digital formats may increase the clarity of information, but this does not replace the need for discussion.

This statement was changed to:

CSCD technology ***can encourage*** *the* ***building of trust*** *to support conflict resolution through increased accuracy, clarity* ***and transparency*** *of communication between team members.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 58%. No experts believed it to be low importance and 42% moderate importance.

5.3.2.14 Competency

The statement created for competency in the questionnaire was:

CSCD technology allows for increased competency through increased accessibility of team skills and experience, reduction of unnecessary information and completeness of messages.

50% of participants agreed with the statement, (12%) three experts disagreed in full and 38% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "There is as much opportunity to fill communication with incomplete or inaccurate messages", which suggests that opportunities can support but cannot guarantee. The requirement statement should reflect this;
- "Only, assuming the appropriate team skills and experience exist in the team" that reflects the skills and experiences which can exist outside the core design team; and,
- "I don't understand what you mean by reduction of completeness of messages?" which is a formatting error and will be changed.

Also, other comments were made that the requirement statement is a "Quite idealistic opinion". This is true as this is the intent of all the statements, but from the feedback it was expected that a "CSCD technology can" statement would be more preferred. "not necessarily (true) when the team members are co-located" which is untrue when technology can be integrated into the collocated space. Finally, an expert contributed, "no, this I cannot agree with: competencies and access to team skills will be there anyhow, whether computer-mediated or F2F (face-to-face)" which is true but the requirement statement does not attempt to compare face-to-face with collocated or say which is better. That is not the purpose of this research.

This statement was changed to:

CSCD technology ***can encourage*** *the* ***development of*** *greater competency through increased accessibility of team* ***and non-team*** *skills and experience, reduction of unnecessary information and* ***supporting*** *the completeness of messages.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 50%. 12% of experts believed it to be of low importance, and 38% moderate importance.

5.3.2.15 Coordination

The statement created for coordination in the questionnaire was:

CSCD technology supports coordination through a shared space for the organisation of work and communication, easy mechanisms for scheduling meetings and to support the even distribution of work.

92% of participants agreed with the statement, no experts disagreed in full and 8% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "CSCD as implemented so far in our technical societies is all about cooperation and coordination", that is valid depending on the model of collaboration invoked, but this does not represent all views, and so it would be wrong to prioritise this in the statement.

This statement was changed to:

CSCD technology ***can support*** *coordination through a shared space for the organisation of work and communication, easy mechanisms for scheduling meetings, and to support the even distribution of work.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 58%. No experts believed it to be low importance and 42% moderate importance.

5.3.2.16 Innovative thinking

The statement created for innovative thinking in the questionnaire was:

CSCD technology encourages innovative thinking through agile systems to support exploration, creativity and quality of outputs.

50% of participants agreed with the statement, (8%) two experts disagreed in full and 42% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- “We find the opposite in our research and have banned CSCD from the design-lab”, that was interpreted to mean that the technology does not exist to support design and represents the current state of CSCD technology in this expert’s opinion; but not its potential or its successes; and does not represent the development of video conferencing tools and shared design spaces;
- “I do agree but (again) it depends on the selection of the appropriate technologies. It is crucial that creativity is not limited by the use of CSCD”, that is included in the change to “can” requirement statements; and,
- “There is no guarantee that CSCD technology 'automatically' generates innovative results...” that is not the intent of the statement and the change to “can” statements addresses this comment.

In addition, other comments were made that “For synthesis, I still find current CSCD technology not that effective. There are [a] lack of tools that would enable synthesis design tools, such as 6-3-5 method, morphological charts etc.to be executed effectively between distributed teams”. This is true, and this highlights a lack of research and development in the field of CSCD,

This statement was changed to:

CSCD technology ***can encourage*** *innovative thinking through agile systems to support exploration, creativity and quality of outputs.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 63%. 12% of experts believed it to be of low importance and 25% moderate importance.

5.3.2.17 Knowledge management

The statement created for knowledge management in the questionnaire was:

CSCD technology supports knowledge management through the organisation of information and communication, the ability to search and retrieve knowledge easily, and autonomy in the distribution of knowledge.

83% of participants agreed with the statement, (4%) one expert disagreed in full and 13% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed were:

- "CSCD capture more knowledge. It rarely if ever captures the rationale behind the facts (knowledge). Absent the rationale (which is why) re-use is largely broken", this may be true and desirable, but the requirement statement does not claim to be impacted by rationale or decision making.

In addition, other comments were made. Firstly that "Knowledge management is a complex question. CSCD can support it, but usually at a basic level". While this may be true, it is also essential to progress research into higher levels, and perhaps this is the issue rather than the current state of the technology. Furthermore, "I think current CSCD tools have a way to go before they do a good job at these functions if they have them at all" which again highlights the importance of research and development of technologies that support CSCD and how disruptive tools may be the answer to future problems.

This statement was changed to:

CSCD technology ***can support*** *knowledge management through the organisation of information and communication, the ability to search and retrieve knowledge easily, and autonomy in the distribution of knowledge.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 71%. No experts believed it to be low importance and 29% moderate importance.

5.3.2.18 Communication

The statement created for communication in the questionnaire was:

CSCD technology supports communication through synchronous multi-threaded and multi-channel software for prompt discussion in a way that supports the context of the message.

79% of participants agreed with the statement, no experts disagreed in full and 21% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "increase of communication channels increases the communication complexity", while this may be true there is a need to segment communications to specific users or teams;
- "It certainly supports communication; however, a concerted effort is required to add the context to communications, and often this takes additional time. Communication is another crucial factor of CSCD", which justifies the need to change the statement to a "can" statement if the information is uploaded; and,
- "Why excluding asynchronous communication from that definition?", which is prominent in the literature and should be included as part of the requirement statement.

In addition, other comments were made: "Communication in the sense of MH per unit time is up. Relevance is effectively down as we are too busy communicating to think". While this may be true, the requirement statement does not claim to represent relevancy, and this is represented by the statement from a perspective of "the context of the message".

This statement was changed to:

CSCD technology ***can support*** *communication through synchronous* ***and asynchronous*** *multi-threaded and multi-channel software for prompt discussion in a way that supports the context of the message.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed that it was of high importance at 63%. No experts believed it to be low importance and 37% moderate importance.

5.3.2.19 Sharing of data

The statement created for sharing of data in the questionnaire was:

CSCD technology reduces complexity in sharing data through integration with data storage systems, reduced file compatibility issues and synchronous live document working with automated tracking and versioning to enable co-creation of documents.

67% of participants agreed with the statement, (4%) one expert disagreed in full and 29% in part. Most experts agreed with the statement, and minor changes were investigated.

Comments of those who disagreed included:

- "In theory it should but in reality, online repository need a lot of managing and organising in order to be effective. Sharing of data is critical in collaborative work", which highlights the importance of managing data which is reflected in the literature and should be included in the requirement statement; and,
- "In my view, CSCD technology even raises complexity, but makes it 'manageable'...", that supports the previous expert's opinion.

This statement was changed to:

CSCD technology ***can support*** *the complexity* ***managing*** *the sharing data through integration with data storage systems, reduced file compatibility issues and synchronous live document working with automated tracking and versioning to enable co-creation of documents.*

When asked how important this requirement statement is for CSCD teamwork, most experts agreed it was of high importance at 79%. No experts believed it to be low importance and 21% moderate importance.

5.3.3 Relative importance of requirements statements

The results of the importance of the statements are displayed in Table 5-3. The scores were created by adding a weighting to the low medium, and high scores and totalling them. A low score was multiplied by one, a medium score was multiplied by two, and a high score was multiplied by three. For example, sharing of data = (0**1*) + (5**2*) + (19**3*) = 67. The weightings of 1, 2 and 3 were chosen as they accurately represented the intentions of the research to establish a single score. If other values of 1, 3 and 5 were chosen there would be no difference to the outcomes of the order of the rank.

The order of the importance is established as: Sharing of data, Shared understanding, Cooperation, Knowledge management, Feedback from stakeholders, Social communication, Knowledge capture, Communication, Overcome boundaries of access, Building of trust, Coordination, Artefact-mediated, Reduce the barriers (Commonality), Decision making, Greater productivity, Innovative thinking, Greater competency, Motivation, and Company structure.

These statements are used within Chapter 6 to represent the requirements of CSCD within the CSCD matrix and to provide statements for engineering design teams to consider and compare with technology functionalities.

Table 5-3: The importance of CSCD statement (Brisco, R. Whitfield, et al. 2019)

Statement category	Low (X*1)	Med (X*2)	High (X*3)	Rank (sum)
Sharing of data	0	5	19	67
Shared understanding	0	7	17	65
Cooperation	1	5	18	65
Knowledge management	0	7	17	65
Feedback from stakeholders	2	4	18	64
Social communication	1	6	17	64
Knowledge capture	0	8	16	64
Communication	0	9	15	63
Overcome boundaries of access	2	6	16	62
Building of trust	0	10	14	62
Co-ordination	0	10	14	62
Artefact-mediated	3	6	16	61
Reduce the barriers (Commonality)	0	11	13	61
Decision making	0	11	13	61
Greater productivity	0	11	13	61
Innovative thinking	3	6	15	60
Greater competency	3	9	12	57
Motivation	4	10	10	54
Company structure	1	16	7	54

5.4 Summary

In Chapter 5.1 the process of verifying the 220 requirements of CSCD is detailed and the creation of categories and subcategories which represent these requirements. Workshops were conducted at academic conferences to establish categories of requirements of CSCD. Five high-level categories were established.

Through an iterative checking process between workshop, 19 sub-categories were established based on the 220 requirements of CSCD. The sub-categories were ranked in order of importance using a questionnaire of academic experts in CSCD.

These categories were transformed into CSCD requirements statements that represented each category and were validated using a questionnaire sent to experts in the field. Experts responded to the survey providing feedback on their agreement with the statement and any changes they suggest.

The requirements of CSCD produced, verified and validated in this research is an original contribution in its form and is significant in its validation. Future researchers will use this list, and the abridged 19 requirements statements to further research in the area.

During the survey of experts to establish the creation of requirements statement, one respondent described the 19 CSCD requirements as “CSCD dogma which once formalised through verification and publication will have a great impact on teaching”. The principles laid out from the existing knowledge can benefit educators on the core knowledge within the field and to form a basis for new techniques, tools and design approaches.

The CSCD requirements statements are used in the evaluation and selection of technology for CSCD. This evaluation and selection method is described in Chapter 6.

6 THE CSCD MATRIX

In this chapter, the CSCD matrix is introduced, its creation is justified, and its development process is documented. The CSCD matrix is a tool to aid the method of technology evaluation and selection, the need for which is justified through the preliminary ethnographic investigation of the GDP described within Chapters 2 and literature review on CSCD described within Chapters 3. The design of the CSCD matrix is based on existing knowledge from the literature and through the development of knowledge in Chapters 2, 4, and 5 including the requirements of CSCD. This chapter acts as a summary of the research thus far, related to the creation of the CSCD matrix and describes the development of the technology evaluation and selection method that is automated and systematic method.

6.1 Development of a technology evaluation method

The literature review established that there is no technology evaluation and selection method suitable for CSCD projects (Chapter 4). As discussed in Chapter 2, the technology available to student design teams changes rapidly. From year to year within the GDP, new technologies were available to students and the popularity of existing technologies changes also. Towards an increasing number of technologies and a dynamic landscape, the literature review did not provide a solution to this problem but did indicate similar tools. This chapter details the creation of such a method using lessons from the literature and research detailed within this thesis thus far.

Chapter 6.1.1. details the creation of the tool which supports technology evaluation as the CSCD matrix based upon the logic of the technology evaluation method. Bringing together the knowledge and research from earlier chapters. From the establishment of the CSCD matrix as an appropriate method, there is a need to handle the data which is used to populate the CSCD matric in a systematic way, this is achieved through automation of the data coding and matrix population as detailed in Chapter 6.1.2.

6.1.1 Creation of the CSCD matrix

The CSCD matrix is the vehicle for which the technology evaluation and selection method is realised. Similar tools focusing on synchronous or collocated collaboration are not suitable for the additional asynchronous and global complexities of CSCD work as established in Chapter 4. This realisation established a gap in knowledge which a technology evaluation and selection method for CSCD could fill academically, but also educationally, supporting the needs of the GDP in evaluating and selecting suitable technology.

To evaluate technology for CSCD, the requirements of the evaluation process need to be established. If possible, technologies are known and to a team, it is desirable to compare these to the requirements of CSCD in order to establish their suitability for CSCD. The work of Germani et al. (2012), Elfving & Jackson (2005), Walter et al. (2016), and Pugliese et al. (2004) offered a solution to this requirement. Each author had developed a successful technology evaluation method based upon HoQ which enables the comparison of customer requirements with technical requirements using a relationship matrix. Authors customised their own HoQ solution for their particular requirements and research context, but in essence; requirements can be compared with technical requirements.

Requirements are the needs and technical requirements are the how's. For technology, *how's* are the functionality that a technology has, referred to as technology functionality.

This established a method for evaluation presented as a conceptual framework. If technologies are identified, and the functionalities of the technologies are established, then the functionalities can be compared to the requirements of CSCD to determine if the requirements are satisfied by the functionalities. This logic of the method is displayed in Figure 6-1. Technologies consist of technology functionality, and technology functionality can satisfy requirements of CSCD.

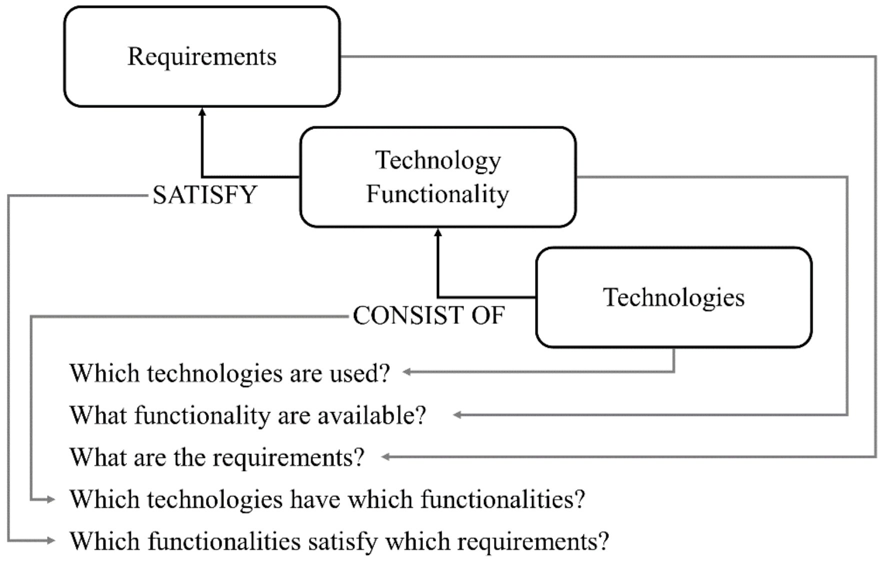


Figure 6-1: Logic of the CSCD matrix

The establishment of this logic leads to five questions. The questions relate to knowledge required for the method or an understanding of the relationship between the knowledge sources. These questions are:

- What technologies are used?
- What functionality is available?
- What are the requirements?
- Which technologies have which functionalities? And,
- Which functionalities satisfy which requirements?

Towards the aim of supporting the GDP, some of this knowledge was known and the remaining knowledge could be established or developed.

Technologies used were known for the previous years of the GDP, however for future projects this would have to be established by the person or team conducting the technology evaluation and selection at the time. This requires a review of available technologies and the ability to characterise these technologies i.e. Facebook is a social network site, Skype is video conference, Google Drive is cloud storage.

Functionalities of technology could be established in two different ways. Either, the technology functionalities may be published in the literature and an available list may be suitable for the purpose of CSCD, or using the GDP data a list of technology functionalities could be established. A published list of technology functionalities should be the first option investigated as a published list is accepted by the research community through a robust peer review process.

Requirements of CSCD could be established through a published list in the literature or through observations of the GDP. Requirements that have been published in the literature have been through a peer review process and are more robust than observations from the GDP, and so this should be the first option investigated. As discussed in Chapter 5, a complete list of the requirements of CSCD was not found, However, many lists were found in the literature. These lists were combined into 220 requirements of CSCD and through a robust verification and validation process with experts in CSCD, 19 requirements statements was established. These 19 requirements statements can be used to determine the requirements of CSCD for the technology evaluation method.

The final two questions require a more complex investigation to determine which technologies have which functionalities and which functionalities have which requirements. To achieve this the logic of HoQ was reviewed.

HoQ enables a comparison of requirements and functionalities, and could in theory offer any other comparison using a matrix between two other concepts, in this case a comparison of technology and functionality. These two comparisons are linked through functionality. Towards this a multi matrix approach was designed.

The technology evaluation and selection method designed was named the CSCD matrix and a template for the matrix is included as Figure 6-2.

Figure 6-2: The CSCD matrix structure adapted from (Brisco et al. 2019)

The CSCD matrix contains two matrices, a matrix to compare the functionality to the requirements (this will be referred to as the functionality-requirements matrix), and another matrix to compare the technologies to the functionalities (this will be referred to as the technology-functionality matrix). Although two matrices are required, they are included in one diagram because the matrices are linked through common functionalities.

If two aspects of the comparison are related, e.g., *Technology 1* and *Technology Functionality 2* in Figure 6-2, then the cell is filled, in with a cross. The same method applies to both matrices. A sum is made on the number of fulfilled and non-fulfilled technology functionalities and CSCD requirements as highlighted in the green cell for the number of related or the red cells for several non-related aspects. The sum indicates quantitatively how a functionality contributes towards the CSCD requirements as a whole or how a requirement is fulfilled.

By populating the matrix, an evaluation of a individual technology or a toolkit of technologies can be made. If an individual technology is used, the matrix can create a profile of this matrix to suggest how well the technology satisfies the CSCD requirements based on its functionalities. If a suite of technologies is used then the profile represents all technologies of the toolkit. This analysis is useful for determining if swapping one technology for another, or the addition of a new technology would benefit the teams collaborative requirements. In addition, the green and red summaries can be used to determine quickly if there is a deficiency for any individual functionality or requirement. This is further described with examples in Chapter 8.

The CSCD matrix is the framework for which an answer can be established. However, there is still a need to answer the five questions in Figure 6-1. What technologies are used?, what functionality is available? And, what are the requirements?, are questions answered in Chapter 6.2 from knowledge identified in the literature or created as part of this research and detailed in earlier chapters.

Following the creation of the CSCD matrix, there is a need to answer the remaining two questions: which technologies have which functionalities? and, which functionalities satisfy which requirements? These questions can be answered with an investigation of a CSCD project, such as the GDP, where students use technologies and their functionalities to satisfy the requirements of CSCD. Collecting data in the GDP on technology use, functionalities of technologies and requirements of CSCD would allow for the understanding of the connections between criteria of the matrices.

The data can be mapped onto the matrixes of the CSCD matrix by identifying data points within the GDP where a technology consisted of functionality, or where a functionality satisfied a requirement. However, to process and code each data point would take a significant amount of time. An automated method was investigated.

The CSCD matrix makes it possible to investigate the reasons why technologies do not meet CSCD requirements enabling an evaluation of the technology. Where the cell between technology functionality and CSCD requirement is filled, there is an enabler to the collaborative process. Furthermore, where the cell is not filled, there are barriers to collaborative design. This relates to the E2 Design activity model, where positive and negative factors that influence CSCD can be identified.

The CSCD matrix supports engineering design teams from the nature of the literature that was used to develop the CSCD requirements. Engineers may find similarities to their own fields and designers also. However, the literature search was specific to this field of CSCD for engineering design teams, and again it is crucial to ensure that the matrix and the outcomes are not generalised. The method that is detailed in this thesis to create the CSCD matrix, code the data and produce the automated methods could be used and updated to apply to other contexts. This could be an expansion of what has been achieved with the CSCD matrix to conduct a literature search with a wider scope, including collocated and blended environments or engineering teamwork in general.

The technologies identified in this research are specific to students use of technology in the GDP. This has a higher number of social network sites being used than in industry as a comparison between the GDP and the technologies in the literature. These types of novel technology tend to fail when integrated into an industry situation (Garcia-Perez & Ayres 2010) due to lack of interest and availability of training for employees. Team groupware technologies are becoming more social, and those available are beginning to mimic social network sites functionality. As students graduate and move into the workforce, they will have skills in modern technology for effective communication using these social network site functionality, and industry should pay attention to these skills. When considering which technologies to evaluate, there should be a consideration of the engineering design team and their skills.

Interest in technology is shown to result in higher levels of engagement (Hank 2012). The CSCD matrix is a tool to ensure not only the novelty and popularity of technologies are essential but the suitability of the technology for the task and the requirements for collaboration.

6.1.2 Requirement for an automated text processing method

As discussed in Chapter 4, identification of technology evaluation and selection methods from the literature, specific knowledge on collaborative design practice is required by the person or team who are using a tool to evaluate and select technology. The method of technology assessment for researchers presented in McAlpine et al. (2011) uses a coding scheme to code specific information about technologies for evaluation. This method enabled for the analysis of project data (14GB worth totalling 68 hours of data collection) using an automated method. This research successfully demonstrated that by using a coding methodology, a large amount of data could be processed into categories for the assessment of individual technologies.

Data collection and processing has been completed in in similar ways for other projects. Hicks (2013) conducted text analysis of company e-mail communications and Gopsill (2014) of student e-mail communication. The work of Hicks and his group at the University of Bristol has demonstrated the use of text processing to create inferences about the design process and the interactions between engineers.

Though analysis of metadata produced by engineering work including, text contained within emails, time spent using technologies during design activities and team member self-categorisation of communications, Gopsill (2014), McAlpine et al. (2011), Snider et al. (2014) and Hicks et al. (2002) have dedicated over 20 years to the understanding of information and knowledge within engineering design projects.

Gopsill et al. (2013) present a method for the data collection of metadata involved in SME engineering. Participants in the study are asked to complete a survey of the communication technologies they used and their frequency. The method was successful in identifying the technologies used and the purpose of their use. This aligned with the technologies and the requirements of CSCD. Gopsill also discusses the functionalities within Gopsill et al. (2013) to determine artefact types and how they are used. In this paper, student social media communications were analysed. A combination of both method, text analysis and surveys were successful in establishing the nature of engineering design communication (Gopsill 2014; Gopsill 2014).

If data can be collected from the GDP in a similar way, then it can contribute towards the understanding of which technologies have which functionalities? and, which functionalities satisfy which requirements?, for CSCD. If this understanding can be automated, then not only will an answer to these questions become easier to determine in the future when technologies available change, but will also enable evaluation of different technology toolkits available to design teams to determine which is best to satisfy the requirements of CSCD in a systematic way.

Data collection was conducted during the GDP class in 2015, 2016, 2017 and 2018. The data collected in 2015, 2016 and 2017 was used to build a repository of statements on students use of technologies during the projects. The data collected in 2018 was used to test the system and validate the method.

The method and process of data collection was employed due to the availability of data from the GDP. No changes were required to the GDP, and no additional design activities were required to be completed by the students. The data collection had no influence on how the teams would collaborate normally, meaning there was no disadvantage to a student's performance in the class and the data was collected for a natural environment. All data was anonymised on the collection of the data.

Students reported the technology use in student reflective reports, and informal interviews which took place weekly as part of the normal coordination of the class. Data was recorded in team diaries by the researcher. This data was used to code diaries and to validate the coding system process.

Reflective reports (further described in Chapter 6.3.1) revealed a wide range of issues related to the collaboration and how technology influenced this collaboration. These were typically related to why software was chosen, the functionalities that technology had, and the affordances of the technology to the collaboration process e.g. the identification that 'Facebook offered communication tools which supported the discussion of concept development'.

Informal interviews with the outcomes recorded in a class diary (further described in Chapter 6.3.2) ensured that common issues in CSCD were recorded. These tend to be resolvable team membership issues or individual technical issues, e.g. unable to contact a team member or if there was an internet outage for a remote team member.

Data collection enabled an understanding for each technology, functionality and requirement and can be mapped into the CSCD matrix in the context of the GDP. To automate this, a method of coding data was investigated. Using a coding scheme such as the one employed by McAlpine et al. (2011), would enable for the coding of known statements about technology to be coded and a dictionary of synonyms to be created. Although synonyms are typically associated with a thesaurus, it is common to refer to this method of representation as dictionaries within the research field.

Dictionaries are required for each category, technology, functionality and requirement, and for each criteria of the categories. The technology and functionality dictionaries are required to populate the technology-functionality matrix, and the functionality and requirements dictionaries are required to populate the functionality-requirement matrix.

To create the dictionaries, an inter-coder method was employed. Three coders with expertise in the inter-coding method and experience of CSCD were asked to code the data of the GDP from 2015-2017 to be used in the automated text processing system. Data from the GDP 2018 was used to validate the method. This overcomes a shortcoming of McAlpine et al. (2011) by involving several coders in the process.

A summary of the knowledge required for the automated population method is included in Figure 6-3. To populate the technology-functionality matrix, the technology and functionality dictionaries are required, and to populate the functionality-requirements matrix, the functionality and requirements dictionaries are required.

A three-step process was developed to support the population of the matrices. First, data from student diaries and reflective reports on the use of technologies that support CSCD within the GDP 2015, 2016, 2017 and 2018 was collected (Chapter 6.3), an inter-coding method and schema developed by three academics was implemented (Chapter 6.4), and third, the creation of dictionaries that support the automated population of the CSCD matrix (Chapter 6.5).

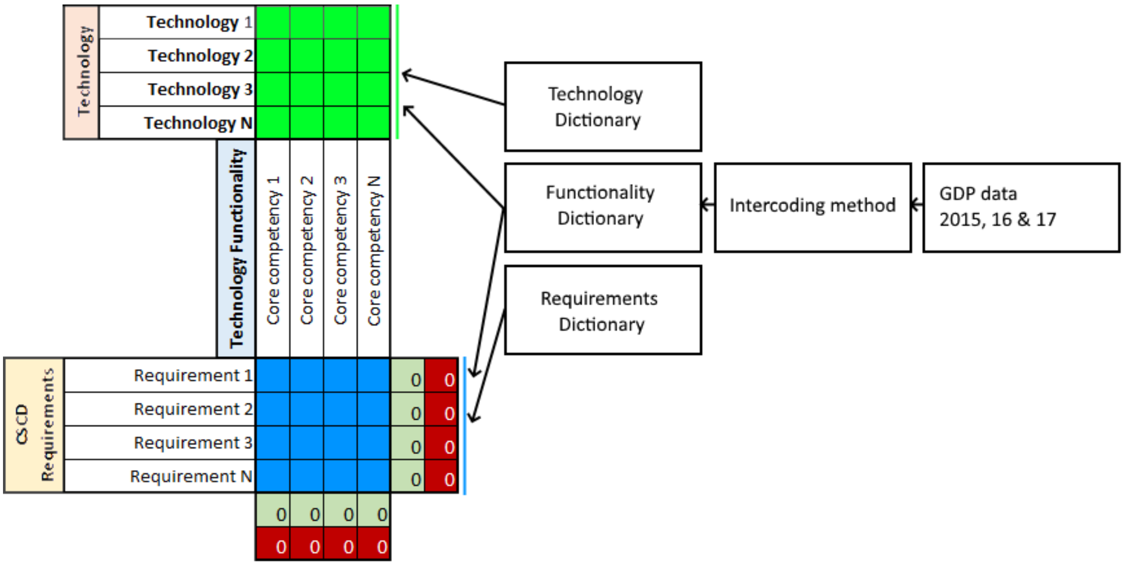


Figure 6-3: Automated population of the CSCD matrix

6.1.3 Systematic population of the CSCD matrix

The final step in the method is to create a system that will automate and systematically populate the CSCD matrix based on the logic of the dictionaries using data from the GDP 2018 to validate the system. To enable the automatic population, software was required with the ability to interpret the data produced in the GDP 2018 within the coding of the dictionaries, and output this as a populated CSCD matrix. This is described as follows.

For each technology, functionality or requirement, a list of synonyms is held in the dictionary, as created during the inter-coding method. The data collected by students during the GDP 2018 is statements of which technologies have which functionalities, or which functionalities satisfy which requirements. By combining these two concepts the CSCD matrix can be populated.

To achieve this, each statement created by students in their reflective report or recorded in the diary is retrieved from a database of the GDP 2018 data. This is processed through filters for any possible coding and the outcomes recorded.

The data from the GDP 2018 must keep specific metadata linked with the individual statements to identify the data throughout the process and troubleshoot the system. From the database, this is the statement to be interpreted (statements) and the metadata code, as discussed in Chapter 6.3.

A software solution is required enabling text processing and coding according to the rules of the dictionaries. Data science platforms enable this functionality and coding. The requirements of this system would be to; retrieve data from a database, split data for multiple coding processes, add new attributes to the data with values, combine data into one database for export, sort based on values for each individual dictionary.

Figure 6-4 displays the requirement of the data science platform and method of text processing as a flow chart. In general, the statements and linked metadata are copied and split between the dictionaries. After processing the statements through the rules and adding any required attributions based on the outcomes of the rules, they are combined and sorted into a final database with headings of technology, technology functionality and CSCD requirement relating to each part of the CSCD matrix.

Within each of the three dictionaries, the statements are copied further to check for specific words of the dictionaries. For example, within functionality, the category of polling tool exists. Investigating the polling tool, there is a need to split the data to check for each of the seven synonyms of a polling tool being: poll, voting, vote, mechanism, activity, functionality, and decision. For each of these synonyms, a match within the statement could be identified. If 'yes', a score of 1 is added. If not, no score is added. In the case of polling tools, all seven synonyms are considered, and the score is all seven synonyms matched would be 7. If only three matched, the score would be 3. Polling tools have the least number of synonyms which is the reason why it is used to provide clear examples.

The largest number of synonyms is the category of shared file repositories at 31 possible synonyms, potentially reaching a score of 31. However, this is unlikely as not every word in a statement would register as a synonym. This score is a confidence score and would be recoded associated with the code for each possible match.

Following the categories and confidence score processing, they are all stored in a database as individual values. The last step in outputting the required data is to export the highest value confidence score for each associated category or export a 0 if there is no category recorded. These are combined into one spreadsheet for each statement represented by the metadata code. This data allows the CSCD matrix to be populated based on the problem or project-specific data submitted.

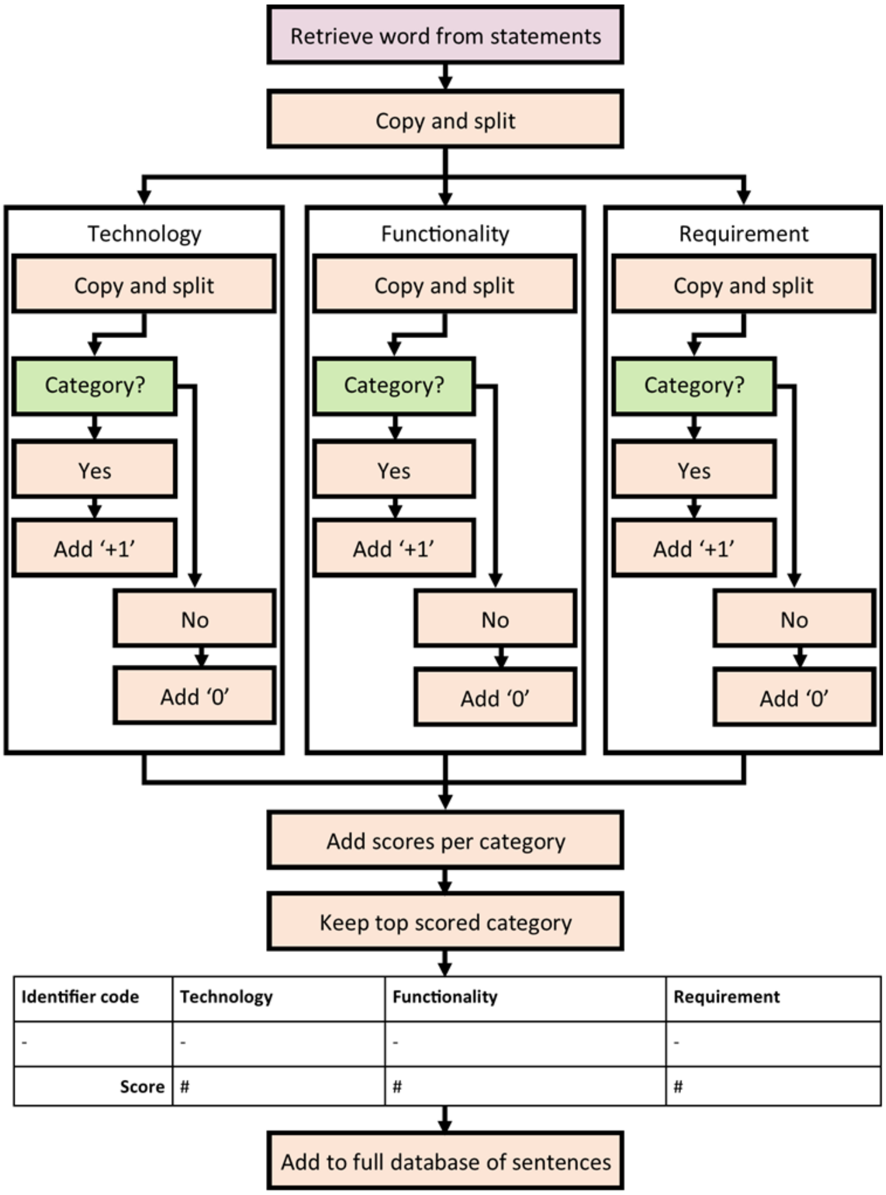


Figure 6-4: Text processing method as a flowchart (Brisco et al. 2019)

The conversion of output data from the text processing method to the CSCD matrix required a simple transfer between spreadsheets. To populate the technology-functionality matrix that calculates technology and technology functionality, the CSCD matrix cell would look for examples of technology and technology functionality linked in the output data. These examples are statements that the automated text processing method has identified both within. For example, if a statement reported the use of Skype to conduct video conference meetings, then the statement would be coded as Skype and video conference, and the cell that links Skype and video conference would display this connection. This is displayed on the CSCD matrix with a green colour. If one connection were found in the data, the value of 1 would be displayed. If no connections were found in the data, they were not linked, and a value of 0 is displayed. This population system mimics binary data storage and allows for the values to be displayed.

The above description of how the CSCD matrix is populated for the technology-functionality matrix is the same for the functionality-requirements matrix, comparing technology functionality and CSCD requirements.

The approach also allows for the CSCD matrix to display the number of connections within a particular category. i.e., where multiple connections are displayed, they can be added together to indicate how successfully criteria such as the CSCD requirements are satisfied. The zero values might also be summated to determine how far away the requirements are from being satisfied or as a comparison. Both of these calculations contribute towards the objectives of the research 'to create an evaluation approach that compares the CSCD requirements against technology functionality to identify suitable technologies for any given CSCD context.' and 'to create an automated and systematic population method towards the evaluation approach.' aligning with the aim.

The outcomes of the automated system mean that the time required to use the CSCD matrix tool is significantly reduced, bias in personal opinion is removed, and less expertise are required to populate the CSCD matrix. This automation does not remove the requirement to have expertise in interpreting the results but does reduce the cognitive load on the individuals. Rather than involvement in populating the method, individuals produce data whilst working on other value creation tasks within their teams.

6.2 The requirements, functionalities and technologies of CSCD

Building upon the established structure of the CSCD matrix, the three different parts of the matrix need to be completed before the CSCD matrix can be used as a tool to evaluate and select technology. Chapter 4 details the investigation of three aspects of the CSCD matrix in the literature, which is supported by the preliminary investigation in Chapter 2, and the creation of the CSCD requirements statements in Chapter 5. This knowledge is used to complete the CSCD matrix.

This chapter summarises the research that has taken place to create the CSCD requirements, the technology functionality that supports CSCD and the technologies that support CSCD, to prepare them for inclusion in the CSCD matrix.

6.2.1 Requirements of CSCD

Chapter 4 details the process of identifying the requirements of CSCD from the literature. 220 requirements were identified for CSCD.

This number of requirements would be difficult to process by an individual or even by a design team. To determine the best technology to use, a team would have to compare one criterion against the 220 requirements. If two criteria were determined then 440 comparisons would be required, and so on. To process these requirements for a single technology would take considerable time and would require in-depth knowledge of each of the 220 requirements by an individual or a team. To simplify the use of the CSCD matrix the number of comparison points was required by creating 19 CSCD statements which represent the 220 requirements.

The 19 CSCD requirements statements are represented in the CSCD matrix by their category name as displayed in Figure 6-5. These 19 categories for the requirements of CSCD are:

1. Complexity managing the sharing of data
2. A shared understanding
3. Cooperation
4. Knowledge management
5. Feedback from stakeholders
6. Social communication
7. Knowledge capture
8. Communication

9. Overcome boundaries of access
10. Building of trust
11. Coordination
12. Artefact-mediated communication
13. Commonality (Reducing barriers)
14. Decision making
15. Greater productivity
16. Innovative thinking
17. Development of greater competency
18. Motivation
19. Integration with company structure

6.2.2 Functionalities of CSCD

Chapter 4 details the literature search and review of this literature to determine the functionalities of technology that can be used to evaluate technology against the requirements of CSCD.

Eight papers were found that propose lists of technology functionality categorisation (Chapter 4). The context of this work varied. Not all related to the specific context of *engineering* and some lists were more general in nature. The lists of technology functionality identified were knowledge management for engineers, CSCW, collaborative design in collocated spaces, collaborative engineering design, collaborative teamwork in education and collaborative systems. With such a wide range for different purposes, there was a need to analyse the lists and determine if any were suitable to evaluate technology against the requirements of CSCD.

Related to the aim of the research in a CSCD context, the technology functionality lists most appropriate for inclusion in the CSCD matrix were those on CSCW, collaborative engineering design and collaborative systems as discussed as follows.

CSCW was appropriate as it is closely related to CSCD but it lacks specific considerations of design. However, perhaps a more general list of functionalities is more appropriate for the identification of functionalities. A whiteboard functionality may be used for design, but it may also be used for team collaboration in other contexts. It may be used for concept drawings or sketches, or it may be used for text-based representations of ideas. The technology itself may be used for many purposes and therefore a generalised list of technology functionalities can be appropriate, particularly if they can be compared to the requirements of CSCD.

Similarly, the lists related to collaborative systems relates to a wider context outside engineering, however, a more general list from a computer science context may also be appropriate.

Collaborative engineering design was the final category and is the context defined in the aim. When defining the literature search, engineering design was a suitable keyword to include. The lists of technology functionality related to engineering design may

To identify which list would be appropriate for inclusion with the CSCD matrix. An investigation was conducted on all technology functionality categorisation lists found in the literature review, by comparing the criteria of the technology functionality with student identification of technology functionality. Chapter 2 describes the technology functionalities identified by students of the GDP and the GS. These were:

- Messaging
- Voting
- Video conferencing
- Profiles
- Networking
- Collaborative document editing
- Electronic whiteboards
- Shared calendar
- Cloud storage
- Task lists

These ten functionalities were compared with the technology functionality categorisation lists as follows:

Mika & Akkermans (2004) present 15 technology actions that can be performed using computer technology within a generic architecture of ontology-based systems. These actions are search, browse, visualise, share, store, transform, reason, secure, version, transfer, extract, learn, edit, merge, evaluate and annotate. These actions do not align with those identified by the students.

The actions by Mika & Akkermans is related to activities that would take place when using functionalities of technology. In messaging, a user may *edit* text, *share* knowledge, *transfer* artefacts. But these are not functionalities. The list by Mika & Akkermans is not suitable as a list of functionalities for the CSCD matrix.

Koch & Gross (2006) presents a functional classification to support decision making when selecting a technology tool. This can be used to support requirements for different aspects of collaboration such as awareness support, communication support, coordination support. Koch & Gross (2006) discusses how these support classifications can be used in CSCW application integration. These therefore represent requirements of collaboration and not the functionalities of technology. Because this list aligns with requirements and not the list identified by students then it is not suitable for the CSCD matrix.

Ostergaard et al. (2003) created a taxonomy of communication within collaborative design activities. The factors of this taxonomy were: team composition (group, individual, team member relations, leadership style, mode,); communication (quantity, syntax, proficiency of team, dependability of resources, intent,); distribution (personal, informational); design approach (design tool applied in each phase, evaluation of progress, degree of structure, process approach, stage); information (form, management, perceived level of criticality, dependability of information); and, nature of the problem (type of design, coupling of sub-tasks, scope, complexity).

This taxonomy is not suitable as a list of technology functionalities due to its focus on communication. Whilst communication is an important aspect of collaboration it does not include aspects such as, shared calendar and cloud storage. The factors within this taxonomy identified closely relate to the Mattessich & Monsey (1992) taxonomy on collaboration requirements i.e. there is a requirement to consider; the quantity of communication (to simplify the communication), the syntax used (to support understanding), the dependability of resources (to contribute to efficient design activities). These considerations are not functionalities of technology. The list by Ostergaard et al. (2003) is not suitable for the CSCD matrix.

This taxonomy is further developed and presented in Ostergaard & Summers (2009) for collaborative design situations. The considerations identified include a mixture of levels such as under distribution (geographically, organisationally, temporally) and mode of communication (verbal, textual, graphical, gestural). These classifications are useful for categorisation but do not reflect the functionalities identified. Again, these are considerations of collaboration and not functionalities of technologies. The list by Ostergaard & Summers is not suitable for the CSCD matrix.

Righter et al. (2017) also built upon the research work of Ostergaard et al. (2003) to report challenges of collaboration within the published literature. The taxonomy had the same structure as Ostergaard et al. (2003) and Ostergaard & Summers (2009) and therefore was also unsuitable for the CSCD matrix.

Gutierrez et al. (2013) present the findings of an investigation into students use of online discussion boards and a general user interface. The functionalities identified such as category (keywords search), tag cloud, contribution and comments, have similarities to those identified by the students of the GDP and GS. This makes it the most promising list identified thus far as it may be suitable for the purpose of comparing technology functionality with the requirements of CSCD. However, the part of the general user interface may be incomplete as it only considers one technology, and also include descriptions of non-functional parts of the interface. Rather than technology functionalities, the parts of the interface appear to be webpage functionalities which is incomplete for the purposes of comparing technology functionalities with requirements of CSCD. The list by Francisco Gutierrez & Baloian is not suitable for the CSCD matrix.

The final list by Mittleman et al. (2015) offers a systems-level list that can be applied to a wide variety of technologies. The classification is named core capabilities of technology and the authors indicate that these competencies can be applied to any collaboration groupware. Groupware and CSCD have many similarities. The list contains: jointly authored pages (shared editors, dynamic group tools, conversation tools, polling tools); streaming media (desktop/application sharing, audio conferencing, video conferencing); and information access tools (shared file repositories, social tagging systems, search engines, syndication tools). There are many similarities between this list and that created by students as compared in Table 6-1.

Table 6-1: Comparison of functionalities identified by Mittleman and students

Functionalities suggested by Mittleman et al. (2015)	Functionalities identified by students
Shared editors	Collaborative document editing
Dynamic group tools	Electronic whiteboards
Conversation tools	Messaging
Polling tools	Voting
Desktop/application sharing	
Audio conferencing	
Video conferencing	Video conferencing
Shared file repositories	Cloud storage
Social tagging systems,	Profiles
Search engines	
Syndication tools	Task lists, Networking, Shared calendar

The functionalities identified by students were completely identified in the list by Mittleman et al. Mittleman identified three additional functionalities being desktop/application sharing, audio conferencing and search engines. Reasons why these may not have been identified, are discussed as follows.

Desktop/Application sharing is a common function of video conferencing technology and the link may have been implicit to the students. Audio conferencing is also often linked with video conference software and is commonly facilitated by telephone conversation within an enterprise setting. Students did not tend to use audio only functionality and preferred the visual communication of video conferencing. It is unclear why searching was not identified by students but perhaps this is a basic functionality that students come to expect with any computer technology and do not consider it unique to CSCD.

From the analysis of the list provided by Mittleman et al. (2015), the list is complete in terms of modern technologies comparing the requirements of the list to the experiences of the GDP and GS. Mittleman et al. (2015) was selected as the only appropriate list of technology functionalities for the evaluation and selection method. No further development to the core capabilities was required.

The core capabilities are described in full in Collaboration Systems - Concept, Value, and Use, Chapter 4, Page 45 available at doi.org/10.4324/9781315705569. It was not possible to procure the permission to reprint the table of core capabilities in this thesis.

The CSCD matrix was updated to include the 11 technology functionalities to support CSCD, as displayed in Figure 6-5.

6.2.3 Technologies of CSCD

Chapter 2 details the process of identifying technologies used in the GDP 2015-2018. Questionnaires were distributed to students which asked students to list the technologies they for personal communication, and those they used during the GDP for project-specific communication. 17 technologies were identified for project communication which supported students in completing their CSCD projects.

In addition to those identified during the GDP, an investigation of technology use reported in the literature during CSCD projects was conducted (Chapter 4). The literature search conducted identified 62 technologies that were used to support CSCD.

Of the technologies identified in the literature, and identified as used in the GDP, seven were identified in both. These are:

- Email;
- Facebook;
- Google Drive;
- Google Hangouts;
- LinkedIn;
- Skype; and,
- WhatsApp.

It was the intention that the technologies could be added to the CSCD matrix. This would mean that the CSCD matrix could be complete with the list of requirements for CSCD, list of technology functionalities and the list of technologies. A design team or decision maker would be able to take this completed matrix and use it to evaluate the technologies and determine the best technology.

However as discussed in Chapter 2, technology changes year to year. A list of technologies published in this thesis may not be an appropriate list of technologies in one years-time. To publish the list of technologies within the CSCD matrix would be a mischaracterisation of the technologies available.

This implication has significant implications for the use of the CSCD matrix. Rather than a completed matrix as intended, at the time of conducting an evaluation and selection of technology, there must be some effort to find potential technologies that are available and accessible. Availability meaning they are able to be used, and accessible meaning the design team have access.

However, to demonstrate and evaluate the CSCD matrix, technologies identified in the GDP would be used to test the method. In future years of the GDP, or indeed other CSCD projects, technologies should be investigated at the time.

6.2.4 The compiled CSCD matrix

Figure 6-5 reveals the compiled CSCD matrix as a tool to evaluate technologies. If only one technology is evaluated, then a profile of that technology can be displayed in the CSCD matrix allowing the user to understand a profile of that technology; the functionalities that the technology has, and how completely the functionalities satisfy the requirements. If an alternative technology were also profiled, then the user could compare both and determine which is best for their CSCD project. A higher number of connections between functionality & requirements means that the requirements are more satisfied.

Alternatively, if multiple technologies are evaluated at the same time, as a tool kit of technologies, then this toolkit can be profiled and compared with the profiles of other toolkits. Individual technologies can be swapped out and new toolkits can be revaluated.

These two scenarios detail the purpose of the CSCD matrix as a tool. If a new team is forming, or an existing team is beginning a new project, then the first scenario is more appropriate. By comparing individual technologies and their alternatives, the team or decision-maker for the team can create profiles and assess the appropriateness of technologies.

If an existing team is continuing a project but perhaps is having issues with their collaboration, then they could profile the technologies they are currently using, substitute alternative technologies and determine if a change in technology would support their CSCD project work better.

In the example of the GDP, which is a project conducted yearly however with new students each edition, a mixture of both evaluations may be appropriate. The knowledge of technologies used in previous editions of the GDP could be reviewed to determine if their profiles are still accurate and if the technologies are still available to students. Any new technologies for evaluation and selection can be profiled and evaluated against the technologies used in previous years. As the editions of the class continue, the technologies may change, but the technology functionalities and the requirements of CSCD will remain the same enabling comparison.

As explained in Chapter 6.1 the CSCD matrix includes a numerical total for the number of functionalities that a technology has, the number of functionalities that satisfy a requirement, and the number of requirements satisfied by a functionality. These totals act as a quick summary for comparison. With the requirements and technology functionalities added to the compiled CSCD matrix, they aid in understanding the matrix in a simplified way compared to the populated matrix itself.

If a technology has 10 of the 11 functionalities, then it is almost a complete tool in terms of functionality. However, there may be scenarios where two technologies contain five of the functionalities each totalling 10 of 11 functionalities. In both scenarios, they would be equally rated in terms of the technology-functionality matrix. Where a decision could be made is in the satisfactory on the CSCD requirements by the technology functionalities e.g. if the single technology profile satisfied 40 of the CSCD requirements cells and the two technologies satisfied 50 then the two tools should be selected. The numerical totals would enable the comparison of the total number of each of the components of the CSCD matrix.

In the scenario above there is a further consideration. If two tools were selected for evaluation, the first tool satisfied 10 of 11 functionalities, and the second tool can satisfy the last remaining functionality, plus has an overlap with another functionality, then there is the possibility for conflict between the technologies. If two technologies offer conversation tools as a functionality then there is the possibility for miscommunication confusion or lack of awareness. A message may be sent one technology, and a response received on the other. This should be avoided, and so, overlapping functionalities should be avoided. Alternative technologies should be investigated.

		Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
Technology	Technology for evaluation 1												0	11
	Technology for evaluation 2												0	11
	Technology for evaluation 3												0	11
	Technology for evaluation n												0	11
	Technology Functionality													
CSCD Requirements	Sharing of data												0	11
	Shared understanding												0	11
	Cooperation												0	11
	Knowledge management												0	11
	Feedback from stakeholders												0	11
	Social communication												0	11
	Knowledge capture												0	11
	Communication												0	11
	Overcome boundaries of access												0	11
	Building of trust												0	11
	Coordination												0	11
	Artefact-mediated												0	11
	Reduce the barriers (Commonality)												0	11
	Decision making												0	11
	Greater productivity												0	11
	Innovative thinking												0	11
	Greater competency												0	11
	Motivation												0	11
	Company structure												0	11
		0	0	0	0	0	0	0	0	0	0	0		
		19	19	19	19	19	19	19	19	19	19	19		

Figure 6-5: The CSCD matrix featuring the 19 CSCD requirements statement categories, the 11 technology functionalities

The other method of using the CSCD matrix is to identify technology requirements. If a CSCD project requires functionality not currently supported by the teams CSCD technology use, they can identify the requirements by determining which functionality would support them. They may then look for new technologies which have only these functionalities, swap out existing technologies for more capable ones, or develop their own technologies to support the requirements.

Students can use the CSCD matrix to evaluate the technologies they may use in their projects based upon the technologies used in 2015 to 2018 and identify the technologies they will use for their projects, and if there are any problems during the projects, potential alternative technologies can be evaluated.

In the past, students did not have the option to analyse and reflect on the technology used for the class but instead selected technologies that they were familiar with. The CSCD matrix enables students to make decisions about how they will manage their projects, the technologies they will use to support this, and the requirements they have as a team to complete design activities. Students must also reflect on the success of these technologies as part of their design activities and the CSCD projects as a whole.

The requirements of CSCD and technology functionalities have been created for the CSCD matrix related to CSCD. They should not be altered or changed to adapt to other contexts. If the tools were to be required for other contexts, the method of the creation of the requirements and functionalities should be followed as detailed in Chapters 2, 4 and 5.

To support student use of the CSCD matrix, a method for the systematic population of the CSCD matrix is developed in Chapters 6.3 - 6.5. To complete this work data collection from the GDP 2015, 2016, 2017 and 2018 from student reports and informal interviews with student teams recorded in a class diary. Data were split into use for coding and preliminary study and testing and for use during a full study to validate and evaluate the method developed. Data collection occurred within the GDP, a coding schema is created using an inter-coding method informing dictionaries of words, to create an automatic text processing method. The results are then presented and discussed.

6.3 Data collection from the GDP class

Students of the GDP at the University of Strathclyde took part in the research. In 2015, 34 students took part in the class; in 2016, 45 students took part, in 2017, 25 students and in 2018, 32 students took part. In total, 136 students participated in the data collection as part of the GDP class.

6.3.1 Reflective report data collection

Students of the GDP at the University of Strathclyde are assessed based upon the reflective reports they submit after the projects conclude. The reports are themed on topics that the students choose, including creativity, culture, information management, leadership, social media and prototyping. The GDP students submit the individually written reflective reports at the end of the 11-week project period. These reports are expected to be written in the style of an academic paper for a journal or an academic conference of around 5000 words. The reports must include a literature review around one-third of the report, and two-thirds of the report is recommended to be on reflection of the project experience and the reflection on lessons learnt during the projects.

The reports typically include documentation of the students' experience participating in the GDP, how they engaged in global teamwork, the development of their concepts and reflection on their experience during the projects. This involves reporting on the technologies that the student teams choose to use to collaborate and their experiences with those technologies. Aspects that are frequently reported by students include: technologies used, and for what purposes; the functionality that supported a design task if a switch in technology was required; how the other students of the team responded to different technologies; the process of selecting technologies; and, problems that emerge with particular technologies.

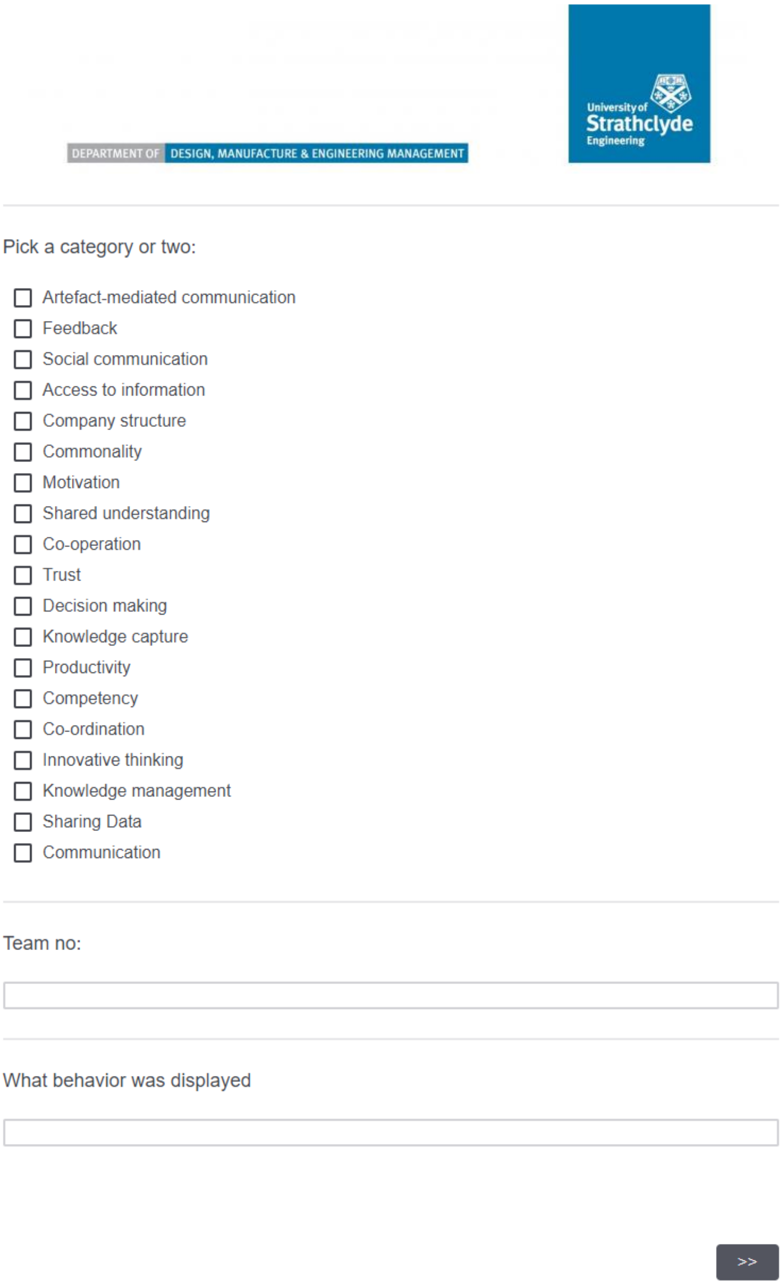
Examples of the statements from student reflective reports and how they were prepared for coding is further discussed in Chapter 6.3.3.

6.3.2 Data collection using informal interviews and student diaries

Students of the GDP class attended lectures each week that introduced them to different aspects of global working to build their knowledge and encourage reflection on their own practices. Following the lectures, there was time for students to discuss their projects and the progress they have been making with the staff involved in the class. This was an opportunity for students to ask for advice to overcome problems they were facing, as well as providing staff with an opportunity to elicit the practical challenges involved in global collaboration.

As part of the discussion between students and staff, informal interviews were conducted between the student teams and the researcher, and a digital diary was used to record any issues that emerged for the GDP between 2015-2017. This diary was populated using a simple textbox on a questionnaire completed by the researcher to record the CSCD related behaviour as reported by students or as observed in students' behaviour. In 2016 and 2017, the data recording was augmented to include data points such as the team number and an initial categorisation based on the CSCD statements. An illustration of the questionnaire used is included in Figure 6-6, displaying how the 19 requirements of CSCD were used to support the collection of data. Frequent reporting by students included: uncertainty in the selection of the right technologies to support their work; problems coming to a consensus with all students on which technology to choose; issues that arise with technologies due to lack of features and functionalities; issues with mobile versions of technologies; issues with human interaction factors exaggerated by technology use; and, miscommunications and successes with particular technologies.

Examples of the statements from student reflective reports and how they were prepared for coding is further discussed in Chapter 7.3.3.



DEPARTMENT OF DESIGN, MANUFACTURE & ENGINEERING MANAGEMENT

University of Strathclyde Engineering

Pick a category or two:

- ☐ Artefact-mediated communication
- ☐ Feedback
- ☐ Social communication
- ☐ Access to information
- ☐ Company structure
- ☐ Commonality
- ☐ Motivation
- ☐ Shared understanding
- ☐ Co-operation
- ☐ Trust
- ☐ Decision making
- ☐ Knowledge capture
- ☐ Productivity
- ☐ Competency
- ☐ Co-ordination
- ☐ Innovative thinking
- ☐ Knowledge management
- ☐ Sharing Data
- ☐ Communication

Team no:

What behavior was displayed

>>

Figure 6-6: Digital form used to collect information on students use of technology during the GDP

6.3.3 Data preparation for coding

Qualitative data analysis software was considered for use in coding and categorising the reflections from the reports in relation to the technology used. NVivo 11 (www.qsrinternational.com/nvivo) was chosen as a software that could enable this categorisation. NVivo enabled reflective statements within the student reports to be tagged with keywords related to the 19 requirements of CSCD, the 11 functionalities of technology or simply as technology when a specific technology was being discussed. The reflective reports were stored in NVivo and organised by year with a numbering system consisting of an initial tag R (Report) and 15, 16 or 17 (year). Using NVivo, the reports were read, and when a paper mentioned one of the following criteria, it was coded accordingly:

- Use of a technology;
- Benefits of a technology;
- Overcoming collaboration barriers using a technology;
- Requirements of a technology; and,
- Considerations for better technology use.

Data from the GDP 2015-2017 was filtered by the research. Due to the smaller amount of data that that produced in 2018, this was achievable. Any data that was not relevant to the criteria above was not coded in NVivo. An example of the coded data is provided in Table 6-2.

Each of the data points was anonymised by assigning a sequential number to the established coding scheme, e.g. R15-1, R15-2 etc. The statement "multi-threaded communication provided structure to conversations.", was first coded with the meta data R15-2 meaning it was a report, for the GDP 2015 and was the second statement in this series. This statement is supported by the identification in Gopsill (2014) for the requirement of communication technologies to support multi-threaded communication.

All statements and codes were extracted and saved as an Excel sheet. The complete list is included in Appendix 10 and is available for download at doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826.

Table 6-2: Sample of entries from student reflective reports

Code	**Statements from students' reflective reports**
R15-1	Preparation of the prototype required a high level of communication and team members to act proactively.
R15-2	Multi-threaded communication provided structure to conversations.
R15-3	Asynchronous communication acted synchronously in situations when required.

Using this approach all of the statements associated with the codes contained within the reports were extracted, resulting with 153 data points related to CSCD in the GDP's.

An example of this data is provided in Table 6-3 that displays the coding. The data points were coded similar to the system employed by the student's reflective reports. Each paper was given an initial tag D (Diary) and 15, 16 or 17 (year). Each of the data points was anonymised by assigning a sequential number to the established coding scheme, e.g. D15-1, D15-2 etc. All statements and codes were extracted and saved as an Excel sheet. The complete list is included in Appendix 11 and is available for download at doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826.

Table 6-3: Sample of entries from informal interview diaries

Code	Statements from class diaries
D15-1	Messenger was used to inform team members where they can access documents.
D15-2	Language difference caused barriers during a video conference. Social network sites being text-based helped to overcome these issues.
D15-3	When video conferencing broke, teams turned to voice memos to summarise completed work in a semi-synchronous method of communication. Allowing for longer and more personalised messages compared to text-based communication.

In total, 123 data points were collected in 2015, 2016 and 2017 related to CSCD in the GDP.

Data from the student reports and the diaries were combined into one Excel document in preparation for the coding of data. A total of 276 statements were collected for the coding process.

6.3.4 Data preparation for testing and evaluation

Data was collected during the 2018 edition of the GDP. This data was collected to demonstrate the use of the overall method with newly collected data. Data was collected from informal interviews with students and recoding in the diary as previously specified. This data was coded as the original data, e.g. D18-1, D18-2 etc. Furthermore, it was recorded anonymously without a team number to remove any bias that individual teams may have towards the data. In total, 208 data points were recorded in the diary.

Students were highly encouraged in the 2018 class to reflect on technological issues that supported the data collection, and a high amount of data could be extracted. Data was coded as before, e.g. R18-1, R18-2 etc. Data was stored extracted from reports and stored anonymously. In total, 5,541 statements were considered for the automated text processing process.

Not all statements were relevant as not all statements were able to link technology use, technology functionality and requirements that are the purpose of the text processing to populate these relationships within the CSCD matrix. Also, some statements were mistakes of the procedure to turn full reports into statements where only one short work or a part of a reference had been mistaken as a full statement. Statements less than five characters were removed. In total, 4,350 statements remained, which contained a link between at least two CSCD matrix categorisations.

All statements and codes were extracted and saved as an Excel sheet. The complete list of 4,350 statements and coding is available for download at doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826.

6.4 Coding of data

Data collected from the GDP 2015, 16 and 17 was coded to support the comparison of the technology and functionality and the functionality with requirements. The coding of this data was a requirement of the automatic text processing system to compare statements on technology, functionality and requirements collected in the GDP 2018 with a coding schema, enabling for the systematic population of the CSCD matrix.

To achieve this, three researchers were asked to perform a coding exercise using an inter-coder method, to individually code the statements collected from the GDP 2015 to 17 academic sessions with their own interpretation towards a coding schema. The coded statements were then discussed and agreed upon between the three authors. The three researchers combined the outcomes of their coding, and where disagreements were found, a discussion and agreement were made.

During the inter-coding process, the specific word or words that influenced the interpretation were also recorded. These words were recorded as dictionaries of synonyms for technology, functionality and requirement. The three dictionaries as an output of this chapter were used to define rules within the automated text processing system to populate the CSCD matrix.

6.4.1 Designing the inter-coder method

Following the data collection from the GDP in 2015, 2016 and 2017, an inter-coder team was formed to perform the coding of the data. The purpose of this team was to independently code the 273 data points collected, and then combine with an attempt to agree on a final coding of the data to support the dictionary building of related terms, that was used to automate the analysis of the text.

Three coders were used to allow a consensus to be formed when two coders disagreed. The third acted as a decision-maker or mediator to arrive at a conclusion. For example, if two coders disagreed, the third coder was asked if they agreed with either of the outcomes. A discussion and negotiation would be held between all three coders in situations where all three coders disagreed, however there was never a situation where this took place.

After the discussion session, it was agreed that the coding was complete, and the coders were in consensus.

The coders were selected because they had experience with collaborative, distributed design projects. They had taken part in at least one global design project as participants and had acted as supervisors to teams in other collaborative design projects. All were PhD researchers and were familiar with the inter-coding method from previous projects.

From data collection, a spreadsheet was prepared with 276 data points and categories for coding. Data was split into coding and testing to support the validation of the method. Each researcher checked 2/3 of the data, and where the coding overlapped, they were checked for agreement or disagreement.

The spreadsheets distributed to the researchers contained the reference code and each statement from either the reports or diaries. A cell for each, technology, technology rationale, functionality, functionality rationale, requirements and requirement rationale

Instructions sent to coders introduced the three parts of the CSCD matrix: Identification of the technology used, identification of functionality offered and identification of collaborative requirement that is supported. Coders were informed that there might not be an answer to all categories, i.e. there may be a statement that discusses technology and functionality, but does not satisfy a requirement, then the requirement and requirement rationale columns would be left blank. As an example, a statement discussing the benefits of Facebook in supporting communication through conversation would be categorised in technology as “SNS”; in functionality as “conversation tool”; and in CSCD requirement as “communication”.

The categories included one cell to write the word identified in the statement taken from the report or diary (rationale) and a defined response on a drop-down menu on specific categories. The 19 CSCD requirements statements define the categories for requirements. Functionality was defined by the 11 technology functionalities originating from Mittleman et al. 2015. Technologies were defined by the list of seven technologies used during the GDP across 2015-2017.

Within each of these categories, coders would have to provide the rationale for their coding. For most, the coder included the word or words from the statement, that supported their decision towards a particular option in the drop-down menu.

Each coder was given 72 data points to code. 36 overlapped with one of the two coders tasks, and 36 overlapped with the other coder’s tasks. Each coder used these categories to associate codes with their 72 statements: technology, technology rationale, functionality, functionality rationale, requirements, requirement rationale.

An example of one of the statements, “Video conferencing facilitated the design process by enabling live discussion on the strengths of each concept”, the following would be extracted:

- “Video conferencing” is a Technology = Videoconference
- “Discussion on the strengths of each concept” is a Requirement = Communication
- "Live discussion" is a functionality = Conversation tool

6.4.2 Outcomes of the coding

The coding task was completed in December of 2018. All coders returned the results after one week. On reflection of the results, one coder did not fully understand the classifications involved in the ‘requirements’ category. As a result, they returned the coding spreadsheet with many blank cells. After a brief discussion around the 19 collaborative requirements, the coder was updated on the requirements and fully completed the task.

When all coding was returned, results were combined into one spreadsheet. Coding between the three coders could be compared. An example of agreed coding examples is included in Table 6-4. A copy of all coding produced is available for download at doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826.

Table 6-4: Examples of agreements between coders

Technology	**Functionality**	**Requirement**
D17-40: Teams discussed how they will communicate for the remainder of the project during a video conference. A synchronous and a synchronous method is being investigated.		
Coder 2 & 3: Video conference	Coder 2 & 3: Conversation tool	Coder 2 & 3: Communication
R16-70: Messenger was difficult to manage team members and knowledge as it kept getting lost.		
Coder 1 & 2: Messenger	Coder 1 & 2: Shared file repositories	Coder 1 & 2: Knowledge management
R16-28: The team used a messenger app to facilitate distributed decision making		
Coder 2 & 3: Messenger	Coder 2 & 3: Polling tools	Coder 2 & 3: Decision making

6.4.3 Coding results and negotiation on changes

The coders agreed on 87% of the 276 data points, with respect to coding the technology, functionality and requirements, and there was no further need to discuss this data. Through cross-validation, the remaining 13% (36 data points) was agreed.

Where disagreements occurred in 13% of the data, these were due to differences in the interpretation of the data. An example is provided in Brisco et al. (2019):

“The use of slack® for multi-channel communication enabling sub-team communication was reported. This was coded by one academic [coder] as a conversation tool and by another as a social tagging system. Both can be applied as slack® is being used for conversations, but communications are being tagged to enable sub-team syndication. Through discussion, the decision was made to code this as tagging, that enabled multi-channel communication and was the intent of the sentence in its original context.”

All discussions to resolve the disagreements were resolved within two one-hour meetings. A list of all disagreements and resolutions is included in Appendix 12. An example of disagreements in coding is included in Table 6-5

Table 6-5: Examples of disagreements between coders

Technology	**Functionality**	**Requirement**
D17-35: Cultural differences made it difficult to communicate a point. Video conference assisted in allowing for visual communication and gestures.		
	Coder 1: Video conferencing Coder 2: Conversation tool	
R15-7: Social network sites offer a less formal place to discuss potential work and to share experiences.		
		Coder 1: Company structure Coder 3: Artefact-mediated communication
R16-38: Google Docs enabled all team members to share data live.		
Coder 1: Collaborative document editor Coder 2: Cloud storage	Coder 1: Shared folders Coder 2: Shared file repository	Coder 1: Sharing data Coder 2: Overcoming boundaries of access Coder 3: Social communication

Following a consensus of the coding, all data was summarised within a spreadsheet for use within the automated population of the matrix. Complete coding data is included in Appendix 13 and is available for download at doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826. The coders identified 486 words across 37 classifications that contribute to understanding the data and can be used to create dictionaries of understanding.

6.4.4 Creation of dictionaries

Three dictionaries were created to correspond to the three conceptual elements of the CSCD matrix: technology; technology functionality; and CSCD requirements. These dictionaries were created to allow an automated text processing system to interpret statements created by the GDP students, categorise them, and populate the CSCD matrix automatically. The dictionaries assisted this process by allowing the text processing method to link known words with categories within the CSCD matrix. Synonyms of words would be used to categorise the statements supplied, with a trust score added.

For each conceptual element of the CSCD matrix, dictionaries were created. The technology dictionary used the technologies identified in the GDP data as categories, and synonyms were collected from the coding.

Technology functionalities dictionary identified synonyms of the functionalities as reported in the GDP data and categorised then to the 11 technology functionalities in Mittleman et al. 2015.

Finally, the requirements dictionary identified synonyms of the requirements reported in the GDP data, categorised by the 19 CSCD requirements statements (Chapter 5).

Within each of the categories, coded words were used as synonyms. For example, within the functionality dictionary, there is a category of polling tools. Within these categories, seven synonyms were found: *poll, voting, vote, mechanism, activity, functionality and decision*. Three of the words *poll, voting and vote* are linked to the category. The words *mechanism, activity, functionality and decision* are not fundamental to the category but are secondary words that assist in identifying if the primary words are in the correct context. As these words were not used within other categories, they support the identification of connections between the dictionaries.

One word, *consensus*, was used by some within a polling context and within a conversation context that could contribute to the category of conversation tools. This is a scenario that the confidence score is designed for. By having additional supplementary words, the confidence of the system can determine more accurate connections.

The dictionaries created and their categories are:

Technology dictionary

- Cloud Storage – Eight terms
- Collaborative Document Editor – Six terms
- E-mail – Two terms
- Messenger – Eight terms
- Social Network Site – Seven terms
- Team Management Groupware – Six terms
- Video Conferencing – Six terms
- Technology functionality dictionary

- Audio Conferencing – five terms
- Conversation Tools – 32 terms
- Desktop/Application Sharing – 11 terms
- Group Dynamics Tools – 21 terms
- Polling Tools – Eight terms
- Search Engines – Three terms
- Shared Editors – Ten terms
- Shared File Repositories – 32 terms
- Social Tagging Systems – Nine terms
- Syndication Tools – Nine terms
- Video Conferencing – 14 terms

And CSCD requirements dictionary

- A Shared Understanding – Nine terms
- Artefact-Mediated Communication – 13 terms
- Building of Trust – 11 terms
- Communication – 13 terms
- Complexity Managing the Sharing of Data – 31 terms
- Cooperation – 15 terms
- Coordination – 23 terms
- Decision Making – Eight terms
- Development of Greater Competency – 16 terms
- Feedback Mechanisms from Stakeholders – Nine terms
- Greater Productivity – 18 terms
- Innovative Thinking – Ten terms
- Integration with Company Structure – 15 terms
- Knowledge Capture – Ten terms
- Knowledge Management – 25 terms
- Motivation – Six terms
- Overcome Boundaries of Access – 16 terms
- Reduce the Barriers of Physical Proximity, Language and Time Zones (Commonality) – 23 terms
- Social Communication – 12 terms

The created dictionaries with synonyms are included in Appendix 14.

6.5 Coding the automated text processing system

The text processing methodology required programming using a suitable computer coding platform. The requirements for this system must match the requirements of the methodology and the skills of the researcher programming and running the coding

The requirements of the methodology are:

- Ability to retrieve data from a database
    - Database in XLSX format
- Ability to split data for multiple coding processes
- Ability to add new attributes to the data with values
- Ability to combine data into one database for export in XLSX format
- Ability to sort based on values

The majority of the requirements above can be satisfied by simple coding Booleans such as: greater than (>), less than (<), =true, =false, +attribute and edit attribute. The complexity required of the system comes from the reuse and combining of data logically. The more complex the coding is, the more difficult the coding is to solve when rules break, e.g., troubleshoot, based on the researcher's skills.

In considering the researcher's requirements in conducting the coding, there was a focus on keeping the processes simple and understandable. The researcher had a basic level of coding skills in HTML, Java and C+. The skills learnt in coding and editing is transferable to other platforms. The requirements for the researcher programming and running the code became simplicity of the programming language and ability to troubleshoot problems logically.

The search began for a data science platform suitable for both sets of requirements. RapidMiner (www.rapidminer.com) was found, that is a platform for tasks such as data preparation, machine learning, text mining and others. RapidMiner uses a graphical interface to code data using pre-made modules. This made the programming of the coding straightforward but did add some time where simple text coding may have been quicker.

One benefit of the RapidMiner visual interface was the ability to converse with others on the coding development. Supervisors to the project and the coders who supported the creation of the dictionaries were consulted to ensure the coding met the methodological requirements. The graphical coding interface enabled quicker understanding and discussion where those involved in reviewing the coding lacked common coding knowledge.

The data is processed through the different dictionaries, categories and words. The software is required to process this data on multiple levels. A top, middle and lower level are stored within folders on the RapidMiner software represented in the GUI as folders. Figure 6-7 displays the top-level code and the data transfer through the folders. Coding is linked from the input on the left to the output on the right. The input being the statements and metadata retrieved from the database using the 'retrieve' module. This knowledge is then split using the 'multiply' module to the three parts of the CSCD matrix: technology, technology functionality, and CSCD requirements. Each of these is a folder that contains further code. When the outputs of each of these folders emerge, it is combined into one output as a spreadsheet.

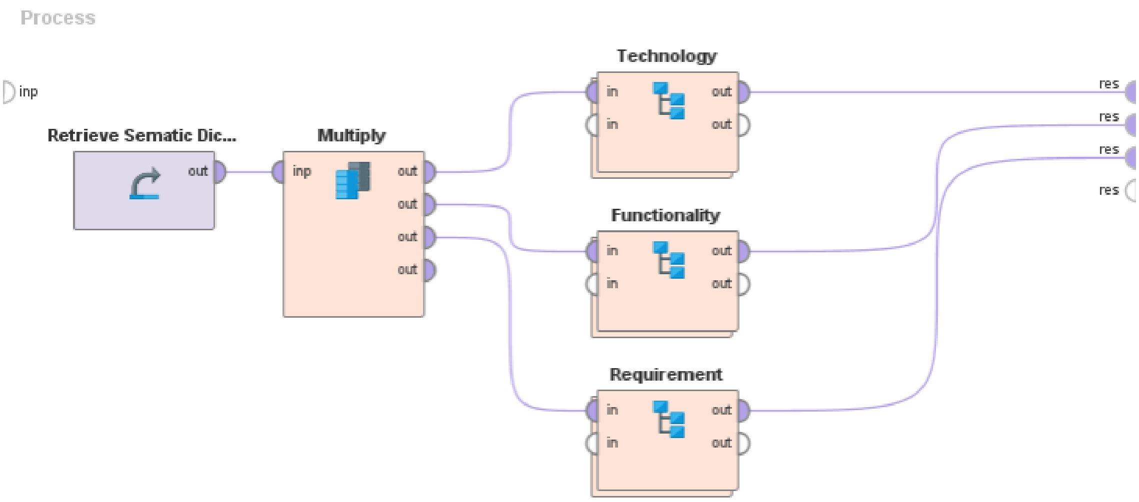


Figure 6-7: Top-level process from RapidMiner

The coding methodology is the same within each of the three folders (technology, functionality, and requirements). The difference lies in the keywords related to each of the dictionaries as created during the coding.

An example of the coding method within each of these folders is provided in Figure 6-8, displaying the technology folder. The technology folder is a middle-level folder. The data from the GDP is further split into each of the category folders. Within each of these folders, further coding takes place, and the output continues onto further filters. If data is linked, it will pass through the 'yes' filter, and if no data is outputted from the folders, it passes onto a 'no' filter, where an attribute of 'none' is added. These filters ensure that when the coding is combined, it does so without ambiguity.

All data is combined with the 'join' command. A first duplicate filter removes all records that contain any codes labelled as 'none' that is incorrect. These are no longer required as only the links are required. These are useful for troubleshooting but not for the population of the CSCD matrix. Data is sorted by code from highest to lowest confidence score to ensure a standardised order and a final duplicate filter removes the lowest confidence score. For example, if social network site was coded as 5, messenger was coded as 3 and video conference was not coded, then; video conference would be labelled as none and removed at the first duplicate filter as two other labels exist. The remaining social network site and messenger labels would be sorted by confidence score, and the lowest scores would be removed at the second duplicate filter being messenger. Thus, leaving only one entry social network site. As a second example. If no coding was achieved, then all possible entries would be marked as 'none', and at the final duplicate entry, only one marked as none would be retained. Then only one entry per statement is included in the export.

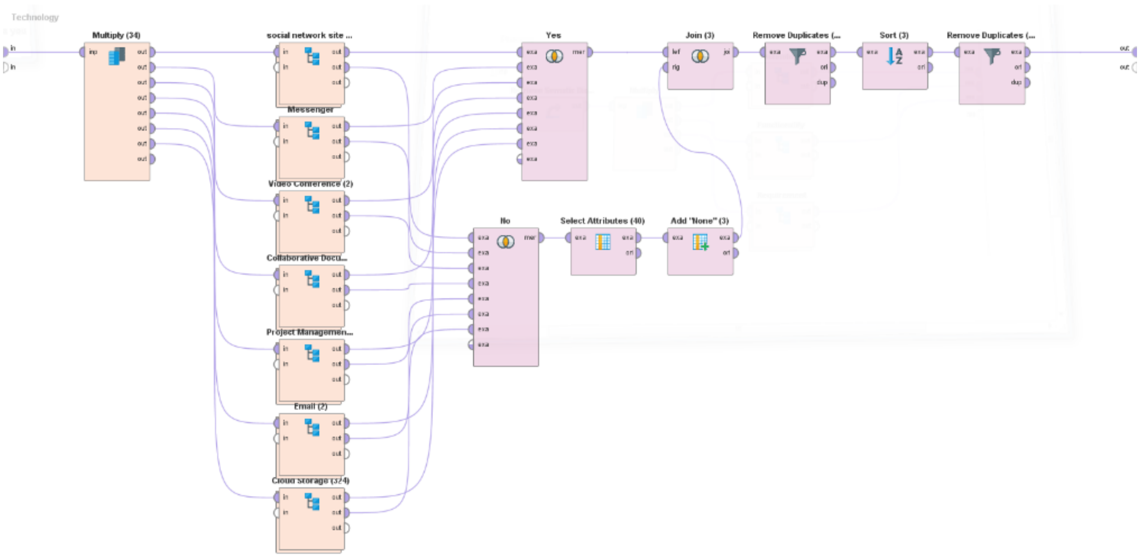


Figure 6-8: Process contained within the technology folder

At the lowest level, inside the folder marked social network site, the individual dictionary terms coding is set up as an example. The input from the database of statements is displayed in Figure 6-9. At this point, the code record has passed through many multiply filters and is further split into seven filters. Each of these filters is a word from the dictionaries. Specifically, the technology > social network site dictionary. Filters are created for 'Facebook', 'network', 'site' etc. As in the middle level, the statements are passed through these filters and export if 'yes' and 'no'. If the statement contains a word, it passes to a 'yes' filter where an attribute is added and saved to the database. In this example, the attribute is a column named 'technology' where the cell is selected and a value of 1 is added. The addition of the numerical value can be done for multiple word filters, and they are summed at this stage to give the confidence score. This passes to the 'yes' combiner in the middle level. If a word is not found, the statement and metadata pass through 'no' and later in the middle level. It is labelled as 'none'.

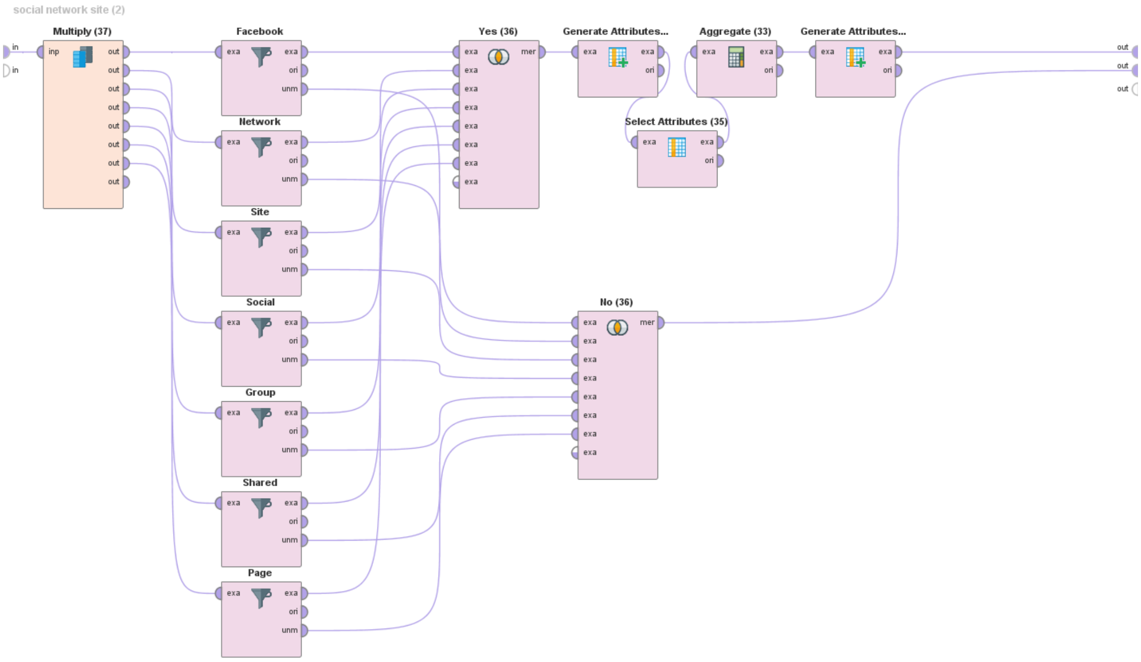


Figure 6-9: Process contained within the category social network site folder

The three filter levels and statements linked with the metadata adds attributes for each of the three parts of the CSCD matrix. The final step returns to the top-level displayed in Figure 6-7, where the three parts output into three databases. Using a combine function once again, these are displayed in one spreadsheet linked by the metadata code. When viewing the output of this process, the links between technology and technology functionality or technology functionality and CSCD requirements are labelled with confidence scores.

6.5.1 Populating the CSCD matrix

Data was exported from RapidMiner in .xlsx format and copied to a sheet within Excel. This excel sheet is linked with a second excel sheet containing the CSCD matrix. This version of the CSCD matrix is capable of the automated population using formulae. A simplified version of the CSCD matrix coding is included in Table 6-6.

Links between categories were used to populate links in the CSCD matrix. The COUNTIFS formula was used to look at the data AKA 'Data Range' within the first sheet and for a specific link word, e.g., email. If a link is found, it is marked within the CSCD matrix. An alternative setup is to pull the confidence scores to the CSCD matrix to display the confidence of the links for multiple levels of confidence. Conditional formatting was used to turn the cell green if a number greater than 0 was inserted into the cell, indicating a link at a glance.

Table 6-6: Example of CSCD matrix population coding within Excel

Technology (Email)	=COUNTIFS(DataRange," Email",DataRange," Conversation Tool")
	Technology Functionality (Conversation Tool)
CSCD Requirements (Cooperation)	=COUNTIFS(DataRange," Conversation Tool",DataRange," Cooperation")

The populated CSCD matrix will display the number of links found as a number, and so if there are X number of links found between 'email' and 'conversation tool' in the exported data, then the number X would be displayed in the cell.

6.6 Pilot study, development and troubleshooting

A pilot study was conceived to test the method of automated population. The pilot used data from the GDP from 2015, 2016, and 2017, the same data used in coding and creating the dictionaries. The pilot study's purpose was to ensure the developed automated method functioned as specified and to help troubleshoot any incorrect programming.

As reported in Chapter 6.3, 276 data points were collected between 2015-2017. 35% of data was used for coding as the minimum required, and 65% was reserved for testing and initial validation. All 276 data points were used during troubleshooting. Figure 6-10 displays the outcomes of this data after text processing.

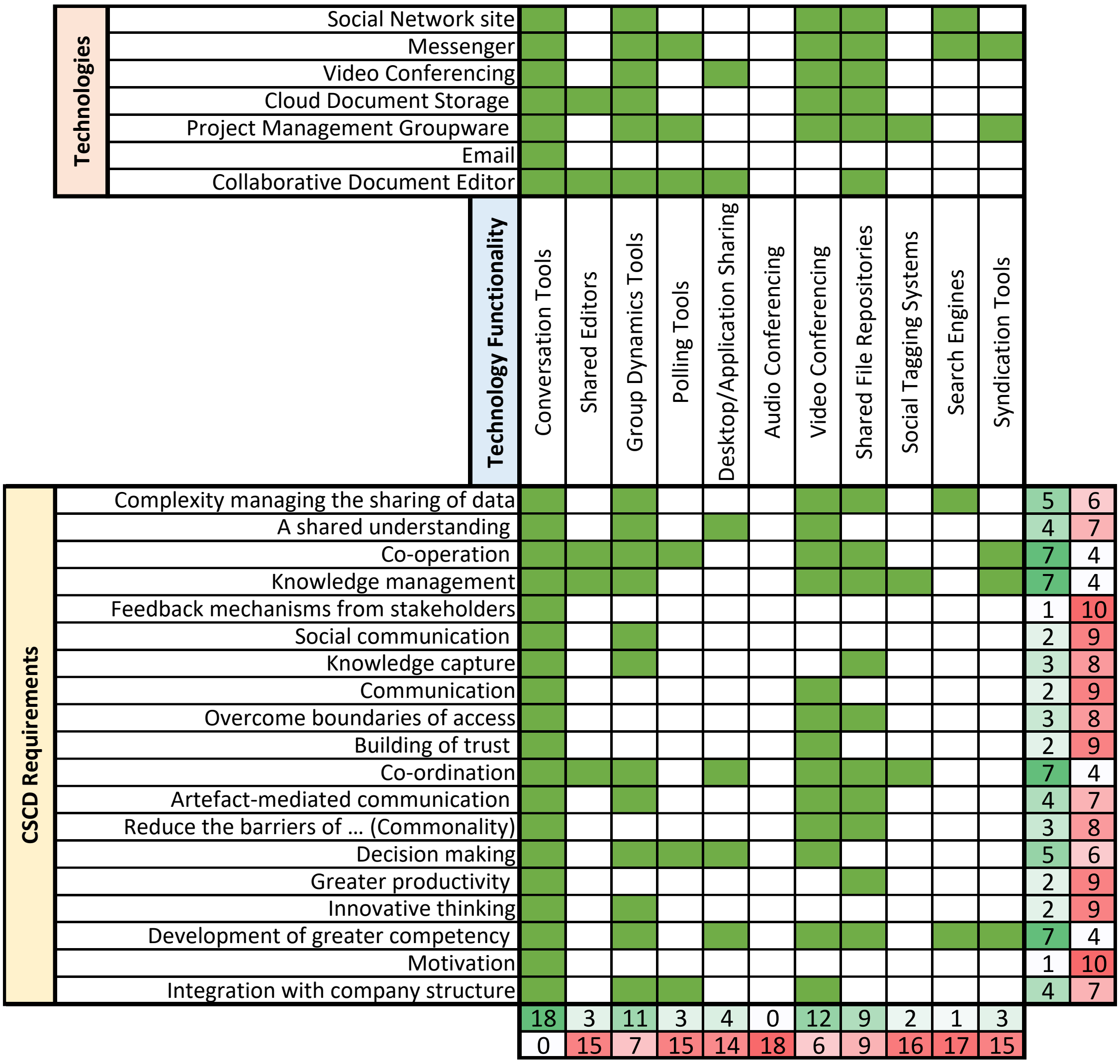


Figure 6-10: CSCD matrix with data from the pilot study (Brisco et al. 2019)

The CSCD matrix displayed in is different to the template displayed in Chapter 6.1.1. At the time of the pilot study, the cells were used to indicate a link. However, the number of connections was not displayed. Also, the number of functionalities that each technology had links with were not totalled, and the confidence scores were not used to display different levels of confidence. Reflecting on the pilot study, each of these features was added to the CSCD matrix as described as follows.

To validate the automated text process method, the output that it created required verification. This verification method required one by one checking of each cell to ensure the processing and population is coded correctly. This method was possible for the GDP 2015,16,17 data but would not be possible for the full set of GDP 2018 data due to the size of the data set and the time required to check the data set.

In addition to validating the method, there was a check to ensure the data matched expectations. The first check was the known non-connections. It was known that there was no data reported on the use of audio conferencing, and generic synonyms of audio conferencing were included in its place. This was checked, and indeed, no connections were identified.

A second validation was to check the unpopulated cells. The result of these could be problems with the earlier coding leading to incomplete dictionaries or incorrect coding. As an example, social tagging systems was only linked with project management groupware in the technology-functionality matrix. It was expected that this would also be linked with social network sites and messengers. Data was found from the GDP that suggested this is correct, but there was no link identified after the automated text processing and population into the CSCD matrix. The lack of a link resulted from incorrect coding where the 'yes' and 'no' outputs were swapped. This solution was to fix the broken code before conducting the full data study. This check was performed on the connections between all cells.

A third validation was performed where syndication tools were not linked to all the expected cells in the functionality-requirements matrix. This error was a result of missing dictionary terms within the automated text processing coding. This solution was to fix the broken code before conducting the complete data study. This check was performed on the connections between all cells.

Whilst working with the pilot study data, it was noticed that having quick knowledge of which technologies meet which functionalities would be helpful in new technology valuation, e.g., if a technology such as email-only offers one function as indicated by the CSCD matrix, then there may be an argument to substitute it for another technology. The score signifies that the functionality has satisfied the CSCD requirements to a greater extent and that minor changes are required to satisfy the requirements of CSCD. Where a low score exists, there are opportunities for alternative or a combination of technologies or techniques to satisfy the CSCD requirements. For the full-text processing, an additional two rows would be included to total the functionalities of each technology.

Upon completion of the validation, outcomes were reflected upon. Technology that supported conversation contributed towards almost all requirements. This outcome was expected because without conversation, and it would be difficult to perform any collaborative task. All technologies that were used within the GDP had some form of conversation functionality. Conversation is the only column that is entirely populated, demonstrating the importance of conversation in all aspects of CSCD. This outcome demonstrates one significant purpose of the CSCD matrix as a tool to evaluate CSCD projects.

From reviewing the data produced by the CSCD matrix, there was a lack of significance conveyed. The CSCD evaluation matrix was automatically populated with the output from RapidMiner, illustrating the relationships between the requirements and technology functionality. However, the cells within the CSCD evaluation matrix can provide a numerical indication of the confidence of the relationship between the two aspects within a cell, illustrating the extent to which the functionality of the technology used within the GDP addressed the CSCD requirements. In order to provide insight to both project managers and computer scientists regarding the barriers in the collaborative process, the significance has to be included in the visual of the CSCD matrix. For the processing of complete data, the number of connections would be included in each cell to signify the probability of a connection.

In addition, there was a need to view the data based on the calculated confidence of the system. For the full-text processing, multiple CSCD matrices would be generated. These will have high, medium and low confidence scores and could be used to evaluate the success of the created method.

The following functionality was added to the CSCD matrix as a result of reflection on the pilot study. Beyond troubleshooting, additional values of the functionality of technology were included. To improve probability analysis, the number of connections between criteria would be included as a numerical value. Finally, to improve evaluation, the confidence scores would be produced on three levels of confidence.

6.7 Summary

In this chapter, the logic of the CSCD matrix is developed that enables technologies, functionalities, and requirements to be compared.

Technologies and their functionalities are displayed with the total number of functionalities per technology totalled. The CSCD requirements and the technical functionalities that satisfy them are compared, and the total number of functionalities that satisfy requirements and vice versa are totalled.

To complete the CSCD matrix template, the 19 CSCD requirements statements created in Chapter 5 were added to the CSCD matrix.

The identification of technology functionality to support CSCD was identified within the current literature and was compared with the functionalities of technologies as identified by students as detailed in Chapter 2. The list of core capabilities by Mittleman et al. (2015) was suitable for the purpose and these 11 functionalities were added to the CSCD matrix.

The identification of technologies that support CSCD was identified in the literature and also from surveying the GDP students. 62 technologies were identified in the literature and 17 from the survey of students. It was decided that due to the nature of change of technology use over time, that technologies would not be included in the compiled matrix Technologies should be canvased for inclusion before using the CSCD matrix

The use of the CSCD matrix is detailed as a technology evaluation and selection tool. Individual technologies can be evaluated, or toolkits can be evaluated altogether. Technologies can be evaluated before beginning a project or technologies can be evaluated for inclusion in concurrent projects as an additional technology available to a team or as a replacement to existing technology.

Data collection and coding are documented to populate the CSCD matrix and evaluate the method. Data was collected from the GDP class across four years. The data was sourced from interviews with students recorded in a diary and reflective reports. Data from both was formalised in a spreadsheet for future use.

An inter-coder method is described to categorise the collected data and develop text processing dictionaries for the method. 276 data points collected GDP in 2015, 2016 and 2017 were coded by a team of three coders. The coders used pre-established categories defined by the CSCD matrix development. 37 categories were established across the three parts of the CSCD matrix. Data collected from GDP 2018 was not used in this process but was retained to validate and evaluate the entire process. In total 4,558 data points were collected for testing and evaluation.

An inter-coder cross-validation method was used to establish that 36% of data would be used for coding, and 64% was reserved for testing and initial validation. An inter-coder method was used to code and agree on the coded data. Each coder was given 72 data points to code. 87% was agreed upon in the first instance, and the remaining 13% was agreed upon through discussion and negotiation.

Following the coding of the data, dictionaries were created of coded data. As statements were coded, a word that includes the coding were extracted. The extracted words formed the dictionaries in line with the categories of the CSCD matrix. 486 words were extracted, which formed the dictionaries.

Towards the automated population of the CSCD matrix, each of the words was assigned a weighting of 1. During the automation process, the weighting was used to create a confidence score based on the number of terms found in a statement. This would enable a future automated system to determine the most likely term from the dictionary when there is a conflict.

The automated text processing methodology is presented. The developed method defines the text processing method and each step to turn the GDP data into a database of coded information. This method enables a confidence score for each data point. The process of splitting and combining the data to produce results was established.

Software was found to enable the coding of the GDP data in an automated way using a data science platform named RapidMiner. This platform enabled text to be categorised and transformed in the way required for the method. Coding was created using a graphical interface to support the researcher's ability and communication of the method with others.

The code developed on the RapidMiner software was layered with the three dictionaries to align with the CSCD matrix. Data is copied and processed until it is categorised with a dictionary term. As the data through levels of coding, it is encoded with confidence scores. The output is a decision for each statement on the technology, technology functionality and CSCD requirement and its confidence for each of these.

After RapidMiner was used to export the data, the results were transferred to an Excel spreadsheet that is designed to populate the CSCD matrix based upon the data. The CSCD matrix uses COUNTIFS functions to calculate the number of links between terms in the data. If a connection is found, the connection is indicated in the cell through a green colour change. This was a simple way to display the outcomes of the data and to interpret the connections.

Using the data from GDP 2015, 2016 and 2017, the text processing and population of the CSCD matrix were tested and validated. Minor changes were made to the code to ensure it functioned as expected. Verification was conducted on the data and the unpopulated cells to ensure the code could accurately process the data using the methodology. An observation was made to display the data in different ways: the different levels of confidence and the change between the levels. Furthermore, the confidence scores would be displayed on the CSCD matrix to understand the significance of the results. The next chapter details the outcomes produced by the auto-population method.

7 TESTING AND VALIDATION

In this chapter, the outcomes of the populated CSCD matrix using data from the GDP 2018 are detailed. The full data set containing 4,558 statements are used. The collection of these data points is described in Chapter 6.3. The population of the CSCD matrix is possible using the systematic, automatic population method as described in Chapter 6.5. The data is displayed in three levels of confidence, and analysis between the levels is conducted.

A sample of the output data is included as Table 7-1 to convey the context of the data export. The sample displays how the code, the statement, the criteria and the confidence score are exported. The full data export from the automated text processing system can be downloaded in excel format from doi.org/10.15129/2ff4c51a-b5e3-43e1-9798-e67d536f5826.

Data was imported to the Excel sheet and duplicated for low, medium and high confidence. The Excel worksheet generates three CSCD matrices based on this data. An exclusion was made within the Excel worksheet when populating the CSCD matrix under the COUNTIF equation to generate these different scores. The low confidence score uses all data greater than 0 (AKA data that indicates a link), medium confidence takes all data with a score greater than 1, and high takes all data with a score greater than 2. Once produced, metadata is generated about the differences between these three CSCD matrices with various levels of confidence. The CSCD matrix with different confidence levels is presented as follows.

Table 7-1: Example data output from the automated text processing method

Code	Sentences	Collaborative Requirements	Req score	Functionality	Fun Score	Technology	Tech Score
R18-3730	The workload and tasks that needed to be completed would be discussed through both social media tools, while all the completed work was uploaded to a shared, collaborative folder within the online cloud storage software called, box	Knowledge management	0.3	Conversation Tools	0.4	Cloud Storage	0.4
D18-208	team created shared documents using google drive	Knowledge management	0.3	Shared File Repositories	0.3	Cloud Storage	0.4
D18-159	team used google drive to share documents live	Knowledge management	0.3	Shared File Repositories	0.3	Collaborative Document Editor	0.4
R18-3335	The group used “Box” to store files and documents in the Cloud	Knowledge management	0.3	Shared File Repositories	0.3	Cloud Storage	0.4
R18-1071	The different approaches resulted through the joint work in a well-reasoned and comprehensive result	(Commonality) Reduce the barriers of physical proximity, language and time zones	0.2	?	?	Messenger	0.1
R18-3274	The disadvantages of asynchronous communication include the following: no immediate feedback, members do not check frequently enough, not enough time for discussion to mature and a lack social disconnection	Feedback mechanisms from stakeholders	0.3	Conversation Tools	0.6	Social Network site	0.1
R18-5365	An interesting part of this topic is how we share information, the language we use and individual’s ways of communicating what they are sharing, through descriptions and annotations on work	Complexity managing the sharing of data	0.3	Conversation Tools	0.6	Collaborative Document Editor	0.1
D18-178	team members shared videos asynchronously for updates	Knowledge management	0.3	Conversation Tools	0.5	Social Network site	0.1
R18-5522	Completed files were uploaded to the shared folder however, many team members did not share all of their files for working or gathering information to use before writing them up	Artefact-mediated communication	0.5	Conversation Tools	0.3	Social Network site	0.1
R18-5492	[2] The sharing of ideas through sketches and descriptions was very time consuming, as not all drawings were well annotated or clear	Complexity managing the sharing of data	0.4	Desktop/Application Sharing	0.3	Collaborative Document Editor	0.1
D18-180	team members uploaded the wrong version of a file delaying the project	Artefact-mediated communication	0.3	Shared File Repositories	0.1	Team Management Groupware	0.1

7.1 Results of the CSCD matrix with low confidence

The CSCD matrix output of the coded GDP 2018 data with a low confidence score is displayed in Figure 7-1. The results of the technology-functionality matrix will be reported from the perspective of the technologies, and the results of the functionality-requirements matrix will be reported from the perspective of fulfilling the CSCD requirements. The matrices have a common understanding of the technology functionality category. The technology functionality offers a significant comparison and more considerable debate of the importance towards the discussion. The following is a discussion of the results;

Of the 286 cells in the low confidence CSCD matrix, 214 registered at least one connection. Within the functionality-requirements matrix comparing technology functionality, two categories recorded 19 connection, three recorded 18 connection, one recorded 16, one recorded 12, one recorded 11, two recorded 10, and one recorded five connections.

Social network sites scored high with conversation tool and moderately in four further categories: shared editor, group dynamic tools, video conferencing and shared file repositories. Polling tools, desktop/application sharing, audio conferencing, social tagging, search engines and syndication tools all scored low. The primary purpose of a social network site is to support communication, and so a confidence score of 271 as a conversation tool is expected. Social network sites support social tagging and syndication; however, these scored lower at two points and three points, respectively.

Messenger scored high in two columns, conversation tools and group dynamic tools, and moderate in all other columns. There was no link recorded between messenger and polling tool. Conversation tools scored 137, and group dynamic tools scored 109.

Video conferencing scored highest in the video conferencing column with 129 connections as expected. Video conference also offered moderate scores in conversation tools and group dynamic tools with scores of 38 and 42, respectively. There were low scores for shared editor, polling tools, desktop/application sharing, shared file repository and syndication tools. No link was recorded for audio conferencing, social tagging systems and search engines.

Cloud storage scored moderately and low for all across the row. Moderate scores were identified between cloud storage and shared filed repositories with a score of 25 and conversation tools with a score of 22. It was expected that both would have a link, but these scores are very low for this technology. All other connections had a low score. No link was found between cloud storage and polling tools, social tagging system and syndication tool.

Team management groupware scored high in the expected areas of conversation tool with a score of 314, group dynamic tools with a score of 340 and a shared file repository with a score of 160. Moderate links included shared editor at 19, desktop/application sharing at 31, video conferencing at 67 and social tagging system at 25. All other scores were lower, but all had a link.

Email scored low across the board. Five links were identified for conversation tool, and two for group dynamic tool and video conference individually.

Finally, collaborative document editor identified its highest number of connections with shared editors at a score of 208. Moderate scores were recorded for conversation tool at 98, group dynamic tools at 46, desktop application sharing at 30 and shared file repository at 44.

		Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
Technologies	Social Network Site	271	32	91	3	6	4	33	39	2	3	3	11	0
	Messenger	137	27	109		18	5	43	28	9	2	5	10	1
	Video Conferencing	38	5	42	1	3		129	8			2	8	3
	Cloud Storage	22	2	5		2	1	4	25		2		8	3
	Team Management Groupware	314	19	340	3	31	7	67	160	25	15	3	11	0
	Email	5		2				2					3	8
	Collaborative Document Editor	98	208	46	1	30		11	44				7	4
	Technology functionality	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
CSCD Requirements	Complexity managing the sharing of data	49	7	71		4	2	3	32		9		8	3
	A shared understanding	60	4	22		4		56	7	1			7	4
	Co-operation	99	36	266	12	21	9	45	37	14	5	3	11	0
	Knowledge management	223	39	140		19	4	42	120	23	3	5	10	1
	Feedback mechanisms from stakeholders	138	4	75		2	1	26	8	1			8	3
	Social communication	47	1	24			1	2	2				6	5
	Knowledge capture	19	4	23		4		7	20		2	1	8	3
	Communication	42	3	11		2		13	4	1			7	4
	Overcome boundaries of access	11	2	4		2		4	16		1	2	8	3
	Building of trust	27	2	10		2		9	10	2	2	1	9	2
	Co-ordination	160	69	182	4	24	4	56	108	12	11	7	11	0
	Artefact-mediated communication	153	14	180	3	15	2	28	13	1	6		10	1
	Reduce the barriers (Commonality)	95	32	47		1	1	17	10		2	1	9	2
	Decision making	62	3	20	15	2		3	3	1	1		9	2
	Greater productivity	9	49	12		9		3				1	6	5
	Innovative thinking	1	2	49				1	2				5	6
	Development of greater competency	51	18	64		15	4	16	13	2	1	1	10	1
	Motivation	1	1						1				3	8
	Integration with company structure	37	10	34	1	3	1	14	13	4	2	6	11	0
		19	19	18	5	16	10	18	18	11	12	10		
		0	0	1	14	3	9	1	1	8	7	9		

Figure 7-1: CSCD matrix with data from GDP 2018 and a low confidence

From the perspective of the CSCD requirements, the key results for the functionality-requirements matrix are as follows.

Complexity managing the sharing of data was linked with conversation functionality with 49 connections, group dynamic functionality at 71 and shared file repositories at 32. Syndication tools and social tagging tools are present when managing the sharing of data, but no links were recorded. Shared editors only scored seven, but this functionality typically refers to live editing.

Shared understanding was linked moderately with conversation tool with a score of 60 and video conferencing with a score of 56. No links were recorded with polling tool, audio conferencing, search engine and syndication tool. Shared editors and desktop/application sharing only scored four individually.

Cooperation was highest linked with group dynamic functionality with a score of 266 and followed by conversation functionality at 99. All others were ranked moderate or low. Shared editing functionality scored 36, video conferencing scored 45, and social tagging functionality scored 14.

Knowledge management scored highest with conversation functionality at 223, group dynamic tools followed at 140 and shared file repository functionality at 120. Social tagging functionality scored 23, search engine scored three, and syndication scored five.

Feedback mechanisms from stakeholders were linked highly with conversation functionality with 138 connections and group dynamic functionality with 75 connections. Video conferencing scored moderately with 26 connections. No connections were found to polling functionality, search functionality and syndication functionality. Shared editing functionality scored low, with only four links.

Social communication scored moderately with a score of 47 on conversation functionality and a score of 24 with group dynamic functionality. No links were found with polling functionality, desktop/application sharing, social tagging functionality, search functionality and syndication functionality.

Knowledge capture had low connections across the board with the highest score of 23 with group dynamic functionality, a score of 20 with shared file repositories and a score of 19 with conversation functionality. Shared editing functionality only had four links.

Communication only scored 42 connections with conversation functionality and 13 connections with video conference functionality. No links were found with audio conferencing functionality.

Overcoming boundaries of access scored low across the row with the highest score of 16 with shared file repository functionality and 11 with conversation functionality.

Building of trust was associated most with conversation functionality with a score of 27, group dynamic functionality and shared file repository functionality with a score of ten for both. Syndication functionality only scored one link.

Coordination scored high for many links across the row. Conversation functionality scored high with a score of 160, as did group dynamic functionality with a score of 182 and shared file repository functionality with a score of 108. Shared editor functionality and video conference functionality were linked with scores of 69 and 56, respectively. Social tagging functionality and syndication functionality had 12 links and seven links.

Artefact-mediated communication was linked highest with group dynamic functionality with a score of 180. Conversation functionality also scored high with 153. Video conference functionality scored 28, shared file repository functionality scored 13 and shared editor functionality scored 14. No link was found for the syndication tool.

Reducing barriers (commonality) scored moderately across the board. It has high links with conversation functionality scoring 95 and moderate with shared editing functionality scoring 32 and group dynamic functionality scoring 47. Shared file repositories had ten connections.

Decision making had its highest connection with conversation functionality at 62. Polling tool functionality scored moderately at 15 connections and group dynamic functionality scored 20. All others were scored low with no connection with audio conferencing functionality and syndication functionality.

Greater productivity was highest linked with shared editing functionality with 49 connections. Conversation functionality only found nine connections. Many non-connections were recorded including polling functionality, audio conferencing, shared file functionality, social tagging functionality and search functionality.

Innovative thinking mainly was linked with group dynamic functionality with 49 connections.

Greater competency was most linked with group dynamic functionality with 64 connections and conversation functionality with 51 connections. Social tagging functionality and syndication functionality only scored two and one connections respectively.

Motivation had very low scores or no connections across the row. Conversation functionality, shared editing functionality and shared file repository functionality scored just one connection each. All other functionalities had no connection.

Integration with company structure had low scores throughout. The highest scores were with conversation functionality at 37 and group dynamic functionality at 34 connections. Social tagging functionality and syndication functionality scored four and six, respectively.

The implications of these critical results are discussed in Chapter 7.4. The main reason for the analysis of the results is to understand if the CSCD matrix automated text processing system was successful in identifying the connections.

The different confidence levels of the CSCD matrix can be used to analyse the results of the automated text analysis. If there is a substantial change in the percentage of the results, it could indicate that the automated text analysis cannot be categorised effectively.

7.2 Results of the CSCD matrix with medium confidence

Figure 7-2 displays the results of the CSCD matrix with medium confidence. The following are key results and changes in score from the low to the medium confidence CSCD matrix.

Social network sites scored higher in one category, conversation tool with a score of 34. The technology scored low for group dynamic tools with five connections, shared file repository with three connections, video conference with two connections and polling tools and desktop/application sharing each had one connection. No other functionalities had a connection, including social tagging system and syndication tool. There were substantial changes with this category of technology as five functionalities no longer displayed a connection. All other functionalities displayed substantial changes.

Messenger scored higher in the column of conversation tool and low in shared editor, group dynamic tool, desktop/application sharing, video conferencing and shared file repositories. No other links were recorded including audio conferencing, social tagging system and syndication tool. Four functionalities no longer recorded with a connection. All other functionalities displayed large changes.

Video conferencing scored highest in the video conferencing column as before with 44 connections. Video conference displayed no link to conversation tools, and group dynamic tools only scored five connections. Shared file repository scored one connection. There were no links for all others, including desktop/application sharing. Five functionalities no longer displayed a connection compared to the low confidence CSCD matrix. All others displayed substantial changes.

Cloud storage held connections with conversation tool and shared filed repositories with scores of 15 and 13, respectively. Group dynamic tools, desktop/application sharing and video conference scored low, and all others displayed no connection. Three functionalities no longer displayed a connection. Conversation tool, desktop/application sharing, video conference and shared file repository did not experience substantial changes from low to medium confidence. However, desktop/application sharing and video conference had low scores within the low confidence CSCD matrix.

Team management groupware scored highest with shared file repository with a score of 54 and moderate scores of conversation tool with 15 connections and group dynamic tools with 17 connections. Four functionalities no longer displayed a connection. This category experiences substantial changes for all other functionality.

Email had no connections with medium confidence.

Finally, Collaborative document editor identified connections with shared editors with a score of 12, conversation tool with a score of 11 and shared file repository with a score of 11. This category of technology lost one connection with polling tool. This technology category experience substantial changes for all remaining functionalities

Technology functionality	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
Technologies													
Social Network Site	34		5	1	1		2	3				6	5
Messenger	36	1	3		2		9	3				6	5
Video Conferencing			5				44	1				3	8
Cloud Storage	15		1		1		3	13				5	6
Team Management Groupware	15	4	17		1		4	54		1		7	4
Email												0	11
Collaborative Document Editor	11	12	1		3		5	11				6	5
CSCD Requirements													
Complexity managing the sharing of data	29		20		4		2	28		4		6	5
A shared understanding	4		1				4					3	8
Co-operation	8		29	1			7	6				5	6
Knowledge management	118	5	47		8		18	100		1	1	8	3
Feedback mechanisms from stakeholders	43	1	39		2		19	4				6	5
Social communication	23		7			1	2					4	7
Knowledge capture	11		5		1			10				4	7
Communication	18	1	5		1		8	2				6	5
Overcome boundaries of access	8		2				3	13				4	7
Building of trust	4						1	3				3	8
Co-ordination	42	2	40		4		14	48			2	7	4
Artefact-mediated communication	93		88	1	10		19	5				6	5
Reduce the barriers (Commonality)	28	3	11		1		9	1			1	7	4
Decision making	11			2			1	2				4	7
Greater productivity	2	9			2		1					4	7
Innovative thinking			32									1	10
Development of greater competency	13		12		2		3	3				5	6
Motivation												0	11
Integration with company structure	7	1	6		1		4	4			1	7	4
	17	7	15	3	11	1	16	14	0	2	4		
	2	12	4	16	8	18	3	5	19	17	15		

Figure 7-2: CSCD matrix with data from GDP 2018 and a medium confidence

Within the functionality-requirements matrix, there were similar fundamental changes from low to medium confidence.

Complexity managing the sharing of data was linked with conversation functionality at 29, group dynamic functionality at 20 and shared file repositories at 28.

A shared understanding had major changes from the low confidence score. There were low links with conversation tool with a score of four, group dynamic tools with a score of one and video conference with a score of four.

Cooperation also had a significant change and was highest linked with group dynamic functionality with a score of 29. Conversation functionality scored eight connections, video conference scored seven connections, and shared file repository functionality scored six connections. Polling tools scored just one connection.

Knowledge management scored highest with conversation functionality at 118, and shared file repository functionality surpassed group dynamic tools with confidence scores of 100 and 47, respectively. Video conferencing remained with a moderately high score of 18.

Feedback mechanisms from stakeholders remained highest linked with conversation functionality with 43 connections and group dynamic functionality with 39 connections. Video conferencing did not drop considerably with a score of 19.

Social communication dropped significantly across the row, with the highest score of 23 on conversation functionality and a score of seven with group dynamic functionality. This was the only connection for the column of audio conferencing with a score of one, and it is worth mentioning that no score was found in the technology-functionality matrix meaning this functionality is not associated with a particular technology according to the medium confidence.

Knowledge capture had small changes, but this row was not highly scored before. Across the row with the highest score of 11 with conversation functionality, Shared file repository functionality scored ten connections. Group dynamic tools was reduced to five connections.

Communication was another low scoring row that had smaller changes. Conversation functionality had 18 connections, and video conference functionality was reduced to eight connections. Group dynamic functionality retained a moderate score for the row of five connections.

Overcoming boundaries of access scored low across the row with the most significant change to the highest scored functionality of the low confidence matrix. Shared file repository functionality scored 13, and conversation functionality scored eight.

Building of trust had some significant changes with conversation functionality, only scoring four connections. Shared file repository scored three and video conference one connection. All other criteria did not have any connections.

Coordination scored high in the low confidence matrix but had significant losses between low and medium confidence CSCD matrices. Conversation functionality scored 42, and group dynamic functionality had a score of 40. Shared file repository functionality received a score of 48. Shared editing functionality and video conference functionality were reduced significantly with scores of two and 14, respectively. Social tagging functionality had no connections, and syndication functionality had two connections.

Artefact-mediated communication was linked with group dynamic functionality with a score of 88. Conversation functionality also scored high with 93. Video conference functionality scored 19, shared file repository functionality scored five and shared editor functionality had no connections. Desktop/application sharing was able to keep a score of ten.

Reducing barriers (commonality) lost many connections, but conversation functionality remained the highest scoring 28. Group dynamic functionality and shared editing functionality scored 11 and nine, respectively. Syndication tools were able to keep one connection.

Decision making had its highest connection with conversation functionality at 11. Polling tool functionality scored low with two connections and group dynamic functionality and no connections. Video conference and shared file repository functionality were able to keep a score of one and two, respectively.

Greater productivity was highest linked to shared editing functionality with nine connections. Conversation functionality only found two connections, but this was not a major change. Desktop/application sharing were able to keep two connections.

Innovative thinking was able to keep its high score with group dynamic functionality with 32 connections. No other connections were found.

Greater competency was lost considerable links with group dynamic functionality reduced to 12 connections and conversation functionality with 13 connections. Social tagging functionality and syndication functionality had no connections recorded.

Motivation had no connections recorded.

Integration with company structure had low scores throughout and lost several connection criteria. The highest scores remained with conversation functionality at seven connections and group dynamic functionality at six connections. Syndication functionality was able to keep one connection.

Technologies \ Technology functionality	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools
Social Network Site	-87%	-100%	-95%	-67%	-83%	-100%	-94%	-92%	-100%	-100%	-100%
Messenger	-74%	-96%	-97%		-89%	-100%	-79%	-89%	-100%	-100%	-100%
Video Conferencing	-100%	-100%	-88%	-100%	-100%		-66%	-88%			-100%
Cloud Storage	-32%	-100%	-80%		-50%	-100%	-25%	-48%		-100%	
Team Management Groupware	-95%	-79%	-95%	-100%	-97%	-100%	-94%	-66%	-100%	-93%	-100%
Email	-100%		-100%				-100%				
Collaborative Document Editor	-89%	-94%	-98%	-100%	-90%		-55%	-75%			

CSCD Requirements \ Technology functionality	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools
Complexity managing the sharing of data	-41%	-100%	-72%			-100%	-33%	-13%		-56%	
A shared understanding	-93%	-100%	-95%		-100%		-93%	-100%	-100%		
Co-operation	-92%	-100%	-89%	-92%	-100%	-100%	-84%	-84%	-100%	-100%	-100%
Knowledge management	-47%	-87%	-66%		-58%	-100%	-57%	-17%	-100%	-67%	-80%
Feedback mechanisms from stakeholders	-69%	-75%	-48%			-100%	-27%	-50%	-100%		
Social communication	-51%	-100%	-71%					-100%			
Knowledge capture	-42%	-100%	-78%		-75%		-100%	-50%		-100%	-100%
Communication	-57%	-67%	-55%		-50%		-38%	-50%	-100%		
Overcome boundaries of access	-27%	-100%	-50%		-100%		-25%	-19%		-100%	-100%
Building of trust	-85%	-100%	-100%		-100%		-89%	-70%	-100%	-100%	-100%
Co-ordination	-74%	-97%	-78%	-100%	-83%	-100%	-75%	-56%	-100%	-100%	-71%
Artefact-mediated communication	-39%	-100%	-51%	-67%	-33%	-100%	-32%	-62%	-100%	-100%	
Reduce the barriers (Commonality)	-71%	-91%	-77%			-100%	-47%	-90%		-100%	
Decision making	-82%	-100%	-100%	-87%	-100%		-67%	-33%	-100%	-100%	
Greater productivity	-78%	-82%	-100%		-78%		-67%				-100%
Innovative thinking	-100%	-100%	-35%				-100%	-100%			
Development of greater competency	-75%	-100%	-81%		-87%	-100%	-81%	-77%	-100%	-100%	-100%
Motivation	-100%	-100%						-100%			
Integration with company structure	-81%	-90%	-82%	-100%	-67%	-100%	-71%	-69%	-100%	-100%	-83%

Figure 7-3: Percentage change comparison from low to medium CSCD matrix confidence scores per cell

The data was calculated differently within Figure 7-3 comparing the percentage change from the low CSCD matrix to the Medium CSCD matrix. White or blank cells indicate no data within the low or medium CSCD matrix. Yellow cells indicate a 100% change or a score of zero in the medium CSCD matrix. This means that a no-confidence score was calculated using the automated text processing method above 1. Green cells indicate the percentage change for each individual cell.

A higher percentage score indicates a more significant change and less confidence in the data. Complexity managing the sharing of data and shared file repositories had a percentage change of just 13%, which is the lowest in Figure 7-3. This represents a numerical connection change from 32 to 28. Although the low percentage would indicate higher confidence, the number of connections is low. Higher percentages indicate more reliably that a substantial change has taken place. Excluding the 100% changes, an enormous change was 98% between Collaborative document editor and group dynamic tools. This difference represents a change in the number of connections from 46 to one. This data will be utilised to understand and analyse the results in Chapter 7.4.

7.3 Results of the CSCD matrix with high confidence

Figure 7-4 displays the results of the CSCD matrix with high confidence. The following are key results or critical changes in score from the medium to the high confidence CSCD matrix.

Social network sites only had one connection with technology functionality. Conversation tools scored one connection.

Messenger had three connections with technology functionality. Video conference had three connections, conversation tools had two connections, and shared file repository had three connections.

Video conferencing had two connections with technology functionality. Video conference scored six connections, and group dynamic tools scored one connection.

Cloud had three connections with technology functionality overall. Seven connections were with shared file repository, three connections were with video conference and three also with conversation tool.

Team management groupware had two connections overall with technology functionality. One of these was with group dynamic tools with one connection, and another was with video conference with one connection also.

Email had no connections with high confidence.

Finally, collaborative document editor retained four connections with technology functionality overall. Two connections were reported with conversation tool and group dynamic tools, video conference, and shared file repository each scored one connection individually.

All technologies were able to show a connection at a high confidence level. However, from the perspective of technology functionality, there were no connections recorded for shared editors, polling tools, desktop/application sharing, audio conferencing, social tagging systems, search engines or syndication tools.

		Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
Technologies	Social Network Site	1											1	10
	Messenger	2						3	1				3	8
	Video Conferencing			1				6					2	9
	Cloud Storage	3						3	7				3	8
	Team Management Groupware			1				1					2	9
	Email												0	11
	Collaborative Document Editor	2		1				1	1				4	7
	Technology functionality													
CSCD Requirements	Complexity managing the sharing of data	6		4		1		2	12				5	6
	A shared understanding												0	11
	Co-operation			3									1	10
	Knowledge management	37		7				4	35				4	7
	Feedback mechanisms from stakeholders	4		3		1			1				4	7
	Social communication	3		2									2	9
	Knowledge capture	1							2				2	9
	Communication	3		2				2					3	8
	Overcome boundaries of access	2							5				2	9
	Building of trust	1							1				2	9
	Co-ordination	7	1	3				1	7				5	6
	Artefact-mediated communication	37		25				4	3				4	7
	Reduce the barriers (Commonality)	5		3				2	1				4	7
	Decision making												0	11
	Greater productivity		1										1	10
	Innovative thinking			5									1	10
	Development of greater competency												0	11
	Motivation												0	11
	Integration with company structure			1				1					2	9
		11	2	11	0	2	0	7	9	0	0	0		
		8	17	8	19	17	19	12	10	19	19	19		

Figure 7-4: CSCD matrix with data from GDP 2018 and a high confidence

The functionality-requirements matrix had much fewer results also from medium to high confidence.

Complexity managing the sharing of data was linked highest with shared file repository functionality with 12 connections. Conversation functionality retained six connections, group dynamic functionality had four, video conference retained two and desktop/application sharing retained one.

Cooperation only had one connection with technology functionality. Group dynamic functionality scored three connections.

Knowledge management was able to keep high scores in conversation functionality and shared file repository functionality with scores of 37 and 35, respectively. Video conferencing scored four connections, and group dynamic functionality scored seven connections.

Feedback mechanisms had four connections in total, with conversation functionality being the highest with four connections. Group dynamic functionality had three, while desktop/application sharing and shred file repositories had one connection each.

Social communication had two connections across the row. Three connections were recorded with conversation functionality, and two connections were recorded with group dynamic functionality.

Knowledge capture had two connections with technology functionality overall. Shared file repository scored two connections, and conversation tools scored one connection.

Communication retained three connections with technology functionality overall. Conversation functionality had three connections, and group dynamic functionality and video conference had two connections each.

Overcoming boundaries of access had two connections overall with the highest being shared file repository functionality with five connections. Conversation functionality scored two connections.

Building of trust scored one connection with conversations tool and one connection with shared file repository functionality.

Coordination was able to keep five connections overall with technology functionality. Seven connections were found with conversation functionality and shared file repository. Group dynamic functionality scored three connections, and shared editor functionality and video conferencing scored one connection each.

Artefact-mediated was able to register two high scores, with conversation tool receiving 37 connections and group dynamic functionality scoring 25 connections. Also, video conference scored four connections, and shared file repository functionality scored three connections.

Reducing barriers (commonality) had its highest connection with conversation functionality with five connections. Three connections were recorded for group dynamic functionality, two for video conference and one for shared file repository functionality.

Greater productivity was able to keep one connection with shared editor functionality.

Innovative thinking retained five connections with group dynamic functionality.

Integration with company structure had two connections overall with technology functionality. One connection was with group dynamic functionality, and the other was with video conference.

The CSCD requirement categories of a shared understanding, decision-making, greater competency, and motivation did not record any connections with technology functionality categories.

	Technology functionality	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools
Technologies	Social Network Site	-97%		-100%	-100%	-100%		-100%	-100%			
Technologies	Messenger	-94%	-100%	-100%		-100%		-67%	-67%			
Technologies	Video Conferencing			-80%				-86%	-100%			
Technologies	Cloud Storage	-80%		-100%		-100%			-46%			
Technologies	Team Management Groupware	-100%	-100%	-94%		-100%		-75%	-100%		-100%	
Technologies	Email											
Technologies	Collaborative Document Editor	-82%	-100%			-100%		-80%	-91%			
CSCD Requirements	Complexity managing the sharing of data	-79%		-80%		-75%		0%	-57%		-100%	
CSCD Requirements	A shared understanding	-100%		-100%				-100%				
CSCD Requirements	Co-operation	-100%		-90%	-100%			-100%	-100%			
CSCD Requirements	Knowledge management	-69%	-100%	-85%		-100%		-78%	-65%		-100%	-100%
CSCD Requirements	Feedback mechanisms from stakeholders	-91%	-100%	-92%		-50%		-100%	-75%			
CSCD Requirements	Social communication	-87%		-71%			-100%	-100%				
CSCD Requirements	Knowledge capture	-91%		-100%		-100%			-80%			
CSCD Requirements	Communication	-83%	-100%	-60%		-100%		-75%	-100%			
CSCD Requirements	Overcome boundaries of access	-75%		-100%				-100%	-62%			
CSCD Requirements	Building of trust	-75%						-100%	-67%			
CSCD Requirements	Co-ordination	-83%	-50%	-93%		-100%		-93%	-85%			-100%
CSCD Requirements	Artefact-mediated communication	-60%		-72%	-100%	-100%		-79%	-40%			
CSCD Requirements	Reduce the barriers (Commonality)	-82%	-100%	-73%		-100%		-78%	0%			-100%
CSCD Requirements	Decision making	-100%			-100%			-100%	-100%			
CSCD Requirements	Greater productivity	-100%	-89%			-100%		-100%				
CSCD Requirements	Innovative thinking			-84%								
CSCD Requirements	Development of greater competency	-100%		-100%		-100%		-100%	-100%			
CSCD Requirements	Motivation											
CSCD Requirements	Integration with company structure	-100%	-100%	-83%		-100%		-75%	-100%			-100%

Figure 7-5: Percentage change comparison from Medium to High CSCD matrix confidence scores per cell

Again, data was calculated to measure the difference between the confidence scores of each cell of the CSCD matrix. Figure 7-5 displays the difference between the medium confidence CSCD matrix to the high confidence CSCD matrix. Again, white or blank cells indicate no data within the low or medium CSCD matrix. Yellow cells indicate a 100% change or a score of zero in the medium CSCD matrix. Dark green cells with a score of 0% indicate no change in percentage. Light green cells indicate the percentage change for each cell.

A higher percentage score indicates a more significant change and less confidence in the data. Complexity managing the sharing of data and video conference, and reduce the barriers (commonality) and shared file repository had no percentage change. Although the low percentage would indicate higher confidence, the number of connections is low, to begin with, scores of two and one, respectively. Higher percentages indicate more reliably that a substantial change has taken place. Excluding the 100% changes, the most considerable change was 97% between social network site and conversation tool. This represents a change in the number of connections from 34 to one. This data will be utilised to interpret the results in Chapter 7.4.

Within the low confidence CSCD matrix, some cells were not populated from the start. This could be because there is fundamentally no link between the requirement and the functionality or the functionality and the technology. Another reason could be that there is insufficient data. This will be explored in Chapter 7.4.

Figure 7-6 displays the non-connections. Polling tools was the most significant column where no links were observed. Of the 19 CSCD Requirements, only five displayed links and these were of a low score. The same could be observed about motivation, with only three of 11 connections links with low scores, and email with also three of 11 scores that were low. These three represent a potential for lack of data in the reporting of the results. However, the possibility for misinterpreted data is possible or that there is fundamentally no link.

A small number of no links is observed in, reduce the barriers (commonality) with two non-links, polling tool and social tagging systems functionality. The link between reduce the barriers and social tagging systems would indicate the possibility for misinterpreted data, or that there is fundamentally no link. A link by link assessment is required as reducing barriers could be improved by a social tagging system using a notification system. Students of the GDP are aware of this, yet, perhaps they have not reported this use in their reports. This representation displays the non-links well, but more exploration is required to discover the reasons behind the data.

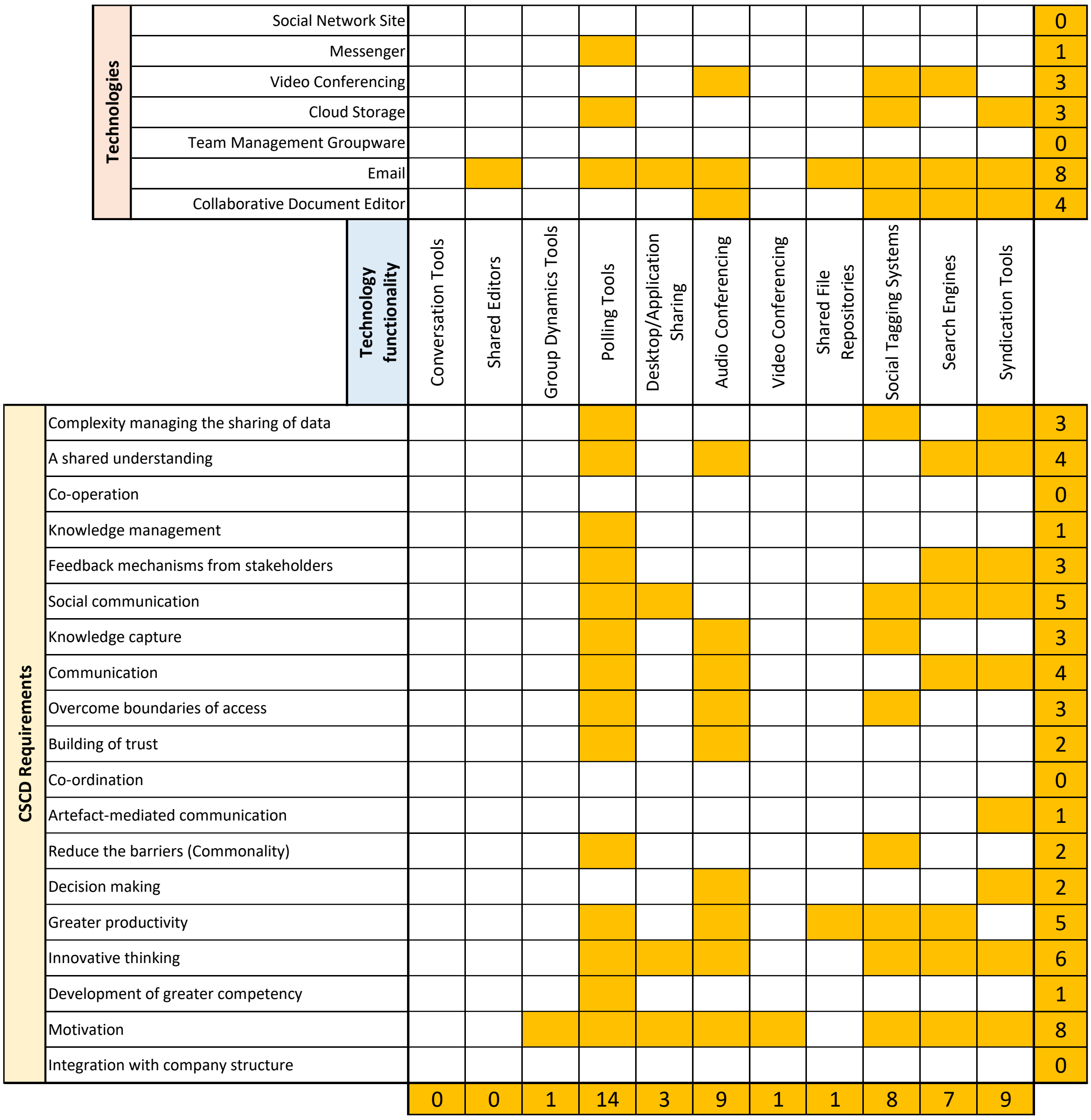


Figure 7-6: CSCD matrix with data from GDP 2018 and a low confidence displaying cells with no link

The low, medium and high CSCD matrix give a great indication of the confidence levels in general. Where a score was measured more significant than 3, this was included in the high confidence CSCD matrix, but it should be indicated for full data transparency.

The highest score in the CSCD requirements category was to reduce the barriers (Commonality), which reached a confidence score of 8 (reference code GDP18R3724). The highest score for the technology functionality category was group dynamic tools that reached a confidence score of 8 (reference code GDP18R860). And finally, the highest score for the technology category was 4 reached by five technologies: cloud storage, collaborative document editor, video conferencing, social network site and messenger (reference codes: GDP18D115, GDP18D159, GDP18D208, GDP18R1872,

GDP18R1899, GDP18R2434, GDP18R3335, GDP18R344, GDP18R3690, GDP18R3730, GDP18R3878, GDP18R4632, GDP18R508, GDP18R5429, GDP18R917 and GDP18R996)

7.4 Reflections for the GDP class

The results of the CSCD matrix, which has successfully processed the GDP 2018 data is presented in Chapter 7.1 - 7.3. The outcomes of the CSCD matrix applies to the development of the GDP 2019 and beyond for continual development based on gaps in students knowledge and future editions of the project. The analysis of the CSCD method also reveals general insights into the CSCD matrix method and its suitability for this analysis. This chapter details some reflections on the GDP that the researcher has observed over the years with evidence supported by the outcomes of the CSCD matrix.

This section will discuss the low, medium and high confidence CSCD matrices produced. These enable validation of the method and not the appropriateness of the matrices for evaluation. As this section will discuss, the high and medium matrix are more accurate in providing an outcome that can be used towards future GDP's such as the GDP 2019 based on observations and analysis of the data.

One of the motivations of this work was the increased use of social network sites within a University environment. These technologies were being used for social communication, and Students utilised them for academic communication to support coordination, cooperation, and collaboration. The outcomes of the CSCD matrix for GDP 2019 demonstrated that social network sites are an excellent versatile tool for CSCD based upon the data produced in the multiple levels of the CSCD matrix. Within the low confidence CSCD matrix, social network sites linked to all technology functionalities. It was identified that they are well suited as a communications tool. However, it should be mentioned that team management groupware scored higher, and messengers that are very popular with students scored lower in their suitability to CSCD requirements.

Considering the technologies students use for communication, there has been a change in student behaviour over the four years of the study. A private Facebook group was a popular option in 2015 for team communication; however, in 2018, it was more common for messengers such as WhatsApp to be used. The class has a high number of postgraduate students from international backgrounds who tend to use WhatsApp more than the Scottish students within the class. However, this does not explain the increase in messengers, as there have always been many students from international backgrounds. Over time, messengers have been preferred as a less formal tool. One reason could be the development of messengers over time to include new functionalities which support team collaboration better where the advanced functionalities that social network sites can provide are not entirely required. The simplicity of a messenger seems to be preferred that an advanced and all-encompassing tool.

This sentiment also applies when considering the popularity of team management groupware, as previously mentioned. These tools are sophisticated and include advanced functionalities to support team awareness. However, students prefer the simplicity of messengers. Over time, different groupware software has been used by students, including Slack and Trello as the most popular in 2018. Interestingly, there has not been a consistent technology between years as new ones emerge, claiming to be better than the last yet seeming to have the same functionality in essence. Some of this technology functionality is simply too advanced for the class, and the students are concerned about having an additional technology to monitor for comments or to have to engage with. Students have a draw to technology that they already use even though they may not be the most complete. The CSCD matrix identifies these gaps, and the student team are then aware of barriers when using certain technologies. Although messengers scored lower as a communication tool, they scored higher than a social network site as a group dynamic tool, as a video conference tool, as a social tagging tool. Perhaps these aspects of technology are more relevant to the students than the ones who scored mediocrely.

Web 2.0 technologies are those who encourage user contribution. Social network sites are an excellent example of Web 2.0 as they rely on user-generated content to make the website attractive. Without user content, there is no reason to browse the website or to revisit. Advanced Web 2.0 technologies also include ways of notifying others or the latest information rather than discovery. These are included as technology functionalities as social tagging systems and syndication tools. In the results of the CSCD matrix for GDP 2018, both of these functionalities scored low for social network sites, messengers and team management groupware. Beyond the low confidence CSCD matrix, neither of these technology functionalities displayed any medium or high confidence connections. This could be because there was a lack of reporting on the importance of social tagging functionality and syndication functionality within students. Informally, students reported the use of tagging to ensure all team members were aware of tasks; however, there was minimal reporting on the importance of these in ensuring a shared awareness of a team. This identifies one area where there is a gap in knowledge from literature towards teaching, and updates are required to instil this within class lectures.

Video conference was reported as a common tool throughout the year's data was collected for the GDP. Although some teams struggle with having enough bandwidth to support an excellent quality video conference, all teams make an effort to find a video conference that works for the team members, the internet connection they have and the device they use. Despite this, video conferencing functionality scored relatively low with video conference technology compared with the highest scored communication tool functionality. 129 connections were recorded for video conference functionality, compared with communication functionality (314). it seemed that video conference functionality and video conference technology would be both highly reported by students and easier to match based on the unique words within the dictionary. However, the abundance of the tool may have an impact on the levels of reporting. If students are familiar with the technology, then perhaps they consider the reporting of these technologies less essential or the abundance of these technologies make them less reportable.

Video conferencing displayed an unexpected outcome considering desktop/application sharing functionality. Only three connections were identified for video conference technology. However, further connections were found for Messenger (18) and team management groupware (31). Although, all these technologies employ this functionality. Perhaps again, the technology is lesser regarded for reporting. The functionality is expected for video conference, but perhaps a surprise when included in messengers and groupware.

Cloud storage had low scores across the row. Although this technology is an essential tool used commonly by students to share information, students perhaps did not report the use of this technology. Cloud storage technology is intrinsically linked to shared file repository functionality; however, it had only 25 connections compared to the technology team management groupware, which had 160 connections. Initially, this was presumed to be a mistake where the coding or the dictionaries were incorrect. Upon review of the statements that were coded, this was not the case. It was noted that very few students reported the use of cloud storage to store and share files. It seems that this connection is common, and therefore, students did not report this type of use. However, when team management groupware software has shared file repository technology built-in, it is more notable.

To remark on the connection between cloud storage and shared file repository functionality reveals how the CSCD matrix could be interpreted. When considering Mamo et al. (2015) in attempting to define a proposed approach in the tools to support successful engineering collaboration, perhaps, in contrast, it is not the technologies that the CSCD matrix analysis can justify. As an alternative, the requirements for a shared file repository defines the requirement for cloud storage in any version. However, it has to be considered if the novelty of the reporting is influencing the outcomes of the CSCD matrix.

Team management groupware is not consistently used in the GDP classes across the years. However, the CSCD matrix highlights that it is potentially the best-suited technology for the GDP teams. Students more commonly use social network sites and messengers because they are known to the students. Groupware technologies have the highest linked connections between technology and technology functionality for conversation tools, group dynamic tools and shared file repositories which indicates that are better suited for use. Students are encouraged to explore technologies to use for the GDP but often resort to those they are familiar with. The data produced by the CSCD matrix can quantify the appropriateness of technologies. The outcomes of this should support teams discussions when choosing a technology and act as a justification for selection.

Team management groupware and social network sites were the only two technologies within the GDP 2018 data that populated the entire row of technology functionalities for the low confidence scores. It highlights that both these technologies are well suited to meet the requirements of global collaboration and that they are well developed with many functionalities to meet a wide variety of requirements.

The outcome of the GDP data 2018 highlighted that email is not a popular tool with students. Because of this, there were few reports of email supporting the collaborative design process. Indeed, this is not true when email use in industry is considered. Email itself is a limited technology. Email clients are developing to include new technologies and functionalities, such as file sharing and easy video conference plugins. However, at its core email does not have advanced functionalities to support collaboration and is another example of where the most popular tool is perhaps not the best for the task. Email had no connections with any functionality within the medium and high confidence CSCD matrix.

There are key outcomes from the data which demonstrate the success of the CSCD matrix auto-population method including collaborative document editors. These were identified with 208 connections to shared editing functionality. There were very few connections with any other technology, that can be verified as shared editors are a unique functionality to these technologies with some plugins for cloud storage. A similar outcome of the functionality can be achieved with social network sites, messengers and team management groupware which is the reason they have also been linked.

The positives outcomes for the method were also visible in the link between team management groupware and group dynamic tools, and the communication tools (social network site, messenger and team management groupware) and conversation tools.

Complexity managing the sharing of data had connections with shared file repository (32) but not as many as conversation tools (49) and group dynamic tools (71). It was expected that managing the sharing of data would link most with a tool that supports the storing of data. However, the data reveals that students reported on where they shared the data rather than where it was stored, and the functionalities offered. Conversation tools are the end-use where data is shared with other team members and students reported on this interaction. Although this was the highest-ranked requirement during the survey, few connections reveal low reporting of this data. This could indicate that students do not regard this functionality as necessary, reporting it less, or perhaps functionality that is abundant and expected receives less reporting.

Shared editor functionality had very few connections (7) to complexity managing the sharing of data. This was surprising as it was expected that sharing data would be more straightforward using a live platform. However, within the GDP, there is a preference for asynchronous working. Students have their own schedules and personal lives to balance. Although it is easy for them to send a simple message in response at almost any time of the day, it is more difficult for them to find the time to meet up for a video conference or to conduct a shared live editing task. Considering the data from the GDP, it seems students did use shared editors for asynchronous working as a single location to store documents. This was challenging for students with weak internet connections who experienced data loss or bad user experience as the website became disconnected. This indicates there is a need to test technology with team members before agreeing to profile within the CSCD matrix. Technology can have the best-suited functionality to support successful collaboration, but if it is not accessible, it may as well have none.

A shared understanding was the second-highest rated CSCD requirements in the survey. However, it also received a lower number of connections. Conversation tools (60) and video conference (56) were expected for this category as understanding comes from communication. It was expected that polling tools would have some influence in ensuring a shared understanding, but there were no connections for these two criteria. Also, desktop/application sharing has a role in displaying artefacts in real-time to support understanding. Nonetheless, only four connections were measured. This could be a lack of reporting by students as there were few connections between the functionality and video conferencing. This may relate to students lack of reporting for common functionalities.

Cooperation had the most connections to group dynamic tools functionality and conversation tool functionality. This was understandable as cooperation needs some form of communication. Similarly, with knowledge management requirements, the functionality of dynamic group tools and shared file repository was expected. Knowledge management requires a repository to store the data that each of these technology functionalities supplies. however, the highest connected functionality as conversation tools with 223 connections. Knowledge management is successful if the data can be transferred. Also, there is a need to understand the data itself as such communication becomes essential. This is especially true for small teams and short-term projects where this plays a part in the effectiveness of the design team.

Knowledge capture is related to knowledge management, and from exploring the data, there seems to be a similarity in the reason for the lower number of connections. Using a shared editor or a recordable functionality is expected to make knowledge capture easier. However, this does not always translate to proper knowledge management. Text can be easily captured, but if the message of the text is not stored in the correct format, it might not be acted upon, and decisions made may be lost. A shared editor is an easy way to record changes to a document and record a document's versions. In order for versions to be observed, they have to be displayed in full. Typically this does not happen within shared editors, and instead, only the latest version and most recent changes are displayed despite all knowledge being captured displaying the rationale.

Social communication is one of the lesser essential requirements when it comes to project work. However, in response to the survey, this requirement was rated as one of the highest and certainly the highest of the social considerations. Social communication contributes to CSCD by building intangible connections between students like trust. It is difficult to quantify these terms, and it was suspected then it would be difficult for students to report on the outcomes of social communication and point towards specific technologies. This result are reflected in the CSCD matrix scores, which are all low across the row of social communication. The highest connected functionality is communication tools at 47 connections. This is reasonable as communication is required. However, there are no other functionalities. This is interesting for future teams to consider how they might encourage social communication and what future functionalities of these technologies might support this.

In many ways, the same can be compared for communication. Social communication was rated much higher than communication in the results of the survey. Within the CSCD matrix, there were a similar number of connections for both requirements across the row and towards many of the same functionalities. Video conference had more connections for communication than social communication, perhaps alluding to the use of video conference for more professional communication and less for socialising. Social communication managed to retain a good number of connections from the low confidence to the high confidence CSCD matrix, particularly with the functionalities of conversation tools and dynamic group tools as expected. The explanation prior suggesting that video was used more primarily for professional communication is reinforced by there being no connections within the high confidence CSCD matrix.

Overcoming boundaries of access scored low scores across the row with the highest connection to the shared file repository. This connection was expected as sharing functionality is required to send files to team members, that supports access to knowledge. Boundaries of access could include functionalities to enable different levels of access to team members or allow viewing of documents and editing for different team members. Access boundaries often apply in an industrial setting where documents are required to be restricted due to copyright and privacy issues and typically does not apply in student design teams where team members can access all documents, so a liberal policy is usually best. There is a need to protect the product development documents from other teams, from the teaching staff before documents are ready and from the general public. This type of access reflecting a private group can be easily managed with technologies by using a private login to access the files. More advanced or specialised technologies such as team management groupware will support access protocols better suited to business interests, and this supports the high number of connections within the technology-functionality matrix between shared file repository and team management groupware.

The building of trust is often misrepresented in the research literature. It is undoubtedly a critical CSCD requirement. However, it can be argued that it is given more recognition and an elevated level of importance because of its intangibility. A lack of trust is sometimes used as a catch-all term when there are problems between team members. Most students interviewed refer to trust as a feeling or a sense that they have on a fellow team member. There are some quantifiable measurements of building trust. For example, over time, trust increases (Morita & Burns 2014) or trust is increased through physical connection (Gibson & Cohen 2004). For short-duration projects like the GDP, there is little time to build trust, but there are fewer issues reported in the data concerning collocated team member problems compared to distributed team member problems. In addition, issues that could be the cause of lack of trust originate from cultural differences. Within the CSCD matrix, it was expected that building of trust would be supported by awareness of other team members and the reliability of team members. These are both supported by social tagging systems and syndication tools. This theory was not confirmed by the CSCD matrix due to the low number of connections.

Similar to the building of trust, reducing the barriers, AKA commonality is another less tangible concept. Time zones can be different, and team members develop difficulty scheduling a working or meeting time. Cultural differences also contribute to this. The CSCD matrix highlights that communication is essential for this. Shared editors and shared file repository functionality might also support asynchronous work. Both these were expected as they allow the teams to conduct work in their own time. It was expected that syndication tools would support commonality considerations; however, there was only one connection to support this.

Coordination and artefact mediated communication both had higher scores and demonstrated the success of the CSCD matrix. In addition to the communication functionalities, Coordination was connected to shared editors, and shared file repositories this was because of students use of these functionalities to store documents containing decisions made and tasks for completion. Also, social tagging systems enable team members to tag each other with upcoming tasks for greater awareness and reminders. Although this functionality had a lower score than the majority of the CSCD matrix, it was one of the higher for this functionality, indicating more confidence in the connection. Although there is an indication, there cannot be a definitive outcome. Artefact-mediated communication had a wide range of connections across the row, most likely because artefacts such as images are used on all platforms to communicate knowledge. This requirement mostly linked with communications technology functionality.

Decision making had one significant outcome beyond the expected conversation functionalities. This was the only CSCD requirement to match with the polling tool functionality column with 15 connections. This was an expected outcome as decisions can be formalised through the use of a polling tool to make decision making democratic.

Integration with company structure had a good range of scores across the row despite being ranked lowest of the CSCD requirements. It was one of the only requirements that connected with syndication tools that support awareness. This connection was expected as awareness of other team members is required to fit team members working practices. Company structure or team/university structure in the case of the GDP relies on the suitability of the software to best fit team protocols, and for this, both conversation and sharing of files are essential to ensure low friction between team members. This is supported by the outcome of the data from the GDP in 2018.

Greater productivity was not well reported on across the possible functionality connections. It is difficult to report on functionalities that improve productivity without doing some form of quantitative study; however, students did report that shared editor's functionality supported their productivity. This was expected as having team members be able to access and work whenever they could, and having that document in a standard easily accessible place would support productivity compared to having to wait for turns or try to find the latest version of a document before starting work. Unfortunately, it seems that when more quantitative analysis of technology functionality is required, the CSCD matrix may not be the best tool. It is more suited for qualitative data input from the team members and the software testers. This sentiment is also reflected in the innovative thinking CSCD requirement and the more significant competency CSCD requirement. Each of these was ranked less important in the survey. However, they are regarded highly by business leaders who encourage use within an enterprise environment. It is perhaps because the ideas of productivity, innovation and competency are in addition to basic CSCD requirements to achieve a higher level. A team cannot have greater productivity if it does not have a shared understanding to begin with.

Motivation had three connections total across its row. This could be explained by a lack of reporting due to the intangibility of the concept of motivation. If this were the case, it would still be expected that social tagging systems and the conversation functionalities would have some connections. This perhaps indicated that motivation is not well coded and that more data was required in this topic for coding and creation of the dictionaries.

The lower CSCD matrix with low confidence displays many answers to the outcomes within the technology-functionality matrix. Conversation tools shared editors, group dynamic tools, video conference and shared file editors all displayed many connections between functionality and CSCD requirements. Polling tools, audio conferencing social tagging systems, search functionality and syndication tools were functionality that did not meet fully meet the CSCD requirements according to the GDP 2018 data.

For most connections in the functionality-requirements matrix, the results are reasonable and understandable. However, polling tools did not connect with many of the CSCD requirements. This might indicate that the auto-population was not sufficiently coded or that the level of data was low. Although both of these could be the case, an argument could be made that the coding is accurate as the highest connection was between polling tool functionality and decision making, which have a close relationship. The other outcome is that perhaps the polling tool simply does not contribute to CSCD for many of the requirements. It is limited functionality in this way. However, with the highest connection of 15, there does still seem to be a lack of data reporting on connections for this functionality.

For audio conferencing, the lack of connections was understandable as teams demonstrated a lack of audio communication when a video was so easily accessible for them and had visual artefacts being shared.

The functionalities of social tagging system, search engine and syndication tools all have low connections compared to the CSCD requirements. Search engines were expected to support shared file repositories in tasks such as managing data, knowledge management, and decision making. Indeed, none of these categories demonstrated any higher number of connections, and so the fault may lie in the coding of information or the reporting of data. The same can be said for the syndication tool as it did not have any connections with a shared understanding, feedback or communication in general. Perhaps these functionalities require more synonyms within the dictionary to be able to capture more connections? Social tagging systems did not have the same problem as the column demonstrated some clear connections. The lower scores are more likely from a lack of data collected, perhaps requiring a more extensive study or encouraging GDP students to report on this functionality more.

Social tagging systems and syndication tools scored no connections within the medium and high confidence CSCD matrix. These functionalities were expected to be highly reported as they are unique and novel, particularly within the context of technologies that support CSCD. Within the context of the motivation of this research project, it was expected that social network sites and new team management groupware tools would highlight the importance of these functions. Perhaps these functionalities are no longer unique in the eyes of this generation. Considering the proliferation of Web 2.0 technologies in 2010 to the GDP projects in 2018, students have had eight years to become used to these functionalities, and in many ways, they have always been available.

Although it was well known that audio conferencing functionality was not used in the sense of audio conferences and telephone calls. There was some use of messengers to send and receive audio messages, that could be asynchronous. This was used when internet bandwidth was low, and video conferencing was not possible. Despite knowing this specific use during the GDP 2018, the high confidence CSCD matrix has no connections, and the medium CSCD matrix has one connection. This was expected to be higher even with the lack of reporting.

Using the data of the low, medium and high confidence CSCD matrix, it was possible to compare the changes between them. Conversation tools and group dynamic tools offer basic conversation and enhanced conversation tools. These two functionalities are certainly the most reported functionality use within the GDP 2018 data. This continues throughout the confidence levels, with the highest confidence matrix offers some insight into the difference between the two tools. As the name suggests, where conversation tools are about conversing, they also support knowledge management and artefact mediated communication through certain functionalities, whereas group dynamic tools are mostly related to artefact mediated communication. They perhaps achieve the same outcome for a team with different approaches.

This purpose of having both conversations tools and group dynamic tools is reflected in the team management groupware row within the high confidence matrix. There are no connections with conversation tools and one connection with group dynamic tools. Considering the data from the GDP 2018 medium and high confidence scores, team management groupware offers both functionalities to converse and to conduct group design and discussions. The difference comes from team managements groupware being better suited to support the requirements of team design activities over a tool like a social network site.

Video conferencing was expected the have many connections with desktop application sharing throughout the confidence levels. However, none are recorded within the medium and high confidence CSCD matrix. This could be a lack of reporting or could be that there was not enough data to code the connection between these two cells. Looking at the GDP 2018 data and the dictionaries that underpin the coding, it could be that more terms are required for a more confident evaluation. Whilst there are entire rows that may be misrepresented such as the apparent polling tools column, this is a very particular cell that requires examination or development with future work.

This is also the case for the connection between collaborative document editor and shared editors within the high confidence CSCD matrix. No connections are displayed, and from consideration of the GDP 2018 data, there appears to be a lack of terms to build a connection.

Cloud storage continues to display a connection with conversation tools throughout the confidence levels. Although there is no chat functionality on this type of software, by sharing documents, there is the ability to converse through asynchronous methods. Looking at the GDP 2018 data, a document can be used as an asynchronous chat, or annotations can be used for a back and forth. This seems to support chat for the purpose of feedback mechanisms for stakeholder.

The functionality-requirements matrix highlighted some exciting results also in the differences between technology functionality and CSCD requirements for the medium and high confidence CSCD matrix. Although managing sharing of data had only 32 connections in low confidence, it retained 28 in medium and 12 in high confidence. The initial number of connections is low and would probably be overlooked. However, consideration across the three confidence levels justifies the CSCD outcomes.

This is also the case for the CSCD requirement of knowledge capture. Only 20 connections were found with shared file repository within the low confidence CSCD matrix. However, the cell managed to keep two connections within the high confidence score.

A shared understanding was one of the highest-rated within the survey but only had some moderate scores within the low confidence CSCD matrix. Moving onto the medium and high confidence CSCD matrix, the number of connections drops significantly and altogether within the high confidence CSCD matrix. This could be related to the idea that the idea of a shared understanding is intangible, and they are difficult for students to report upon. Concerning the GDP 2018 data, this appears to be the case.

Cooperation manages to retain its connection with Group Dynamic Tools throughout all levels of the matrix. This supports the expected outcome of global collaboration. Group dynamic tools were expected to be a significant functionality for design teams to cooperate on concurrent shared tasks. There are many examples of tools such as shared whiteboards or similar technologies, being used to facilitate that which might represent a shared tabletop, where synchronous design activities can take place.

Knowledge management managed to retain high connections throughout the confidence scores, mainly with conversation tool functionality (37) and shared file repository functionality (35). Although the number of connections for shared file repository was relatively low within the low confidence CSCD matrix at 120, compared to conversation tools at 223, In the high confidence matrix, the outcomes demonstrate the expectation that the use of a shared file repository tool is crucial to knowledge management.

Feedback mechanisms from stakeholders had a significant drop in the number of connections across the confidence scores. One of the lowest number connections between feedback mechanisms and desktop application sharing (2) in the low confidence, was able to hold onto the same number of connections in the medium and dropped to one in the high confidence CSCD matrix. Although scores can be low throughout, the difference in confidence indicates that there is some importance to those with a lower number of connections. The difference in confidence levels could extract this significance. The same could be indicated for the building of trust.

The CSCD requirement of communication displayed a low number of connections within the low CSCD matrix. This is perhaps due to the mundaneness of communication functionality. However, connections were retained within the high confidence CSCD matrix with communication tools (3), group dynamic tools (2) and video conference (2) as expected.

Overcoming boundaries of access successfully identified a connection with shared file repositories in the high confidence matrix. This was not expected and it could highlight the importance of communication tools for all distributed teamwork with all tools.

Coordination was able to retain a connection with a score of two within the medium confidence matrix with syndication tools. This was the highest score for this functionality but demonstrated a significant connection between awareness and coordination.

Artefact-mediated communication has one of the highest scorers in the medium and high confidence scores across the rows. There are a high number of connections with conversation tools (37) and group dynamic tools (25). This demonstrated that the reporting within the GDP 2018 class towards building the data set had a focus on reporting how the students conducted their design activities through artefacts being shared online.

Reducing the barriers AKA commonality identified the common communication tools within the medium and high confidence scores as expected. Decision making, greater competency and motivation all had no connections in the high confidence CSCD matrix. Within the medium confidence CSCD matrix Greater competency retained a connection with communication and decision making with communication tools. This perhaps alludes to the lack of reporting by students on less apparent connections. It takes some analysis to understand the importance of individual connections, and students perhaps do not have the time to reflect within the class. To overcome this, students can be prepared better to identify when these connections happen so that they might better understand the significance of the connections.

Productivity was able to retain a connection with shared editors within the medium confidence CSCD matrix and one connection with high confidence, which is a clear connection. This is a beneficial identification as the CSCD requirements towards the bottom of the list were also difficult ones for students to identify connections. The same can be remarked for innovative thinking that identified 32 connections in medium confidence CSCD matrix and five connections in the high confidence CSCD matrix with group dynamic tools. This could suggest that group dynamic tools functionality has the most substantial connection with innovation and could be an investigation for future research.

Integration with company structure appears to be most related to communication and file sharing within the Low confidence CSCD matrix. This importance is also reflected within the medium confidence CSCD matrix where shared file repository functionality can keep its connection. This could be due to the importance of documentation and protocols when establishing teams. Unfortunately, this category is not well represented by the GDP class due to the short project length and team formation. A more extended project may provide more data, or perhaps a project with multiple outcomes where students can build their skills and trust over time.

7.4.1 Difference between CSCD matrix confidence levels

From investigating the differences between the low, medium and high confidence CSCD matrix that were produced with the GDP 2018 data, it could be argued that the difference between the different levels should not be considered as low = bad and high = good, or that high is better than the medium which is better than low. The connections between the connections and the confidence of the system go beyond this subjectivity.

A high confidence score indeed means there is belief, but this connection is not always guaranteed. A low confidence score means that there is less confidence in the result, but a higher number of connections means there is more guarantee of the connection being in place. To fully understand the entire picture that the CSCD matrix is creating, there is a need to understand each of the CSCD matrix individually and to pull the knowledge that comes from this understanding together to make decisions.

This is how the CSCD matrix and automatic population method are designed to pull in data from appropriate sources and have someone who is educated in CSCD requirements understand the results. An education method is discussed in Chapter 8.

A further impact from the GDP 2018 is in analysis between confidence levels. From reflection between the low and medium, and medium and high confidence levels of the CSCD matrix, we can determine consistent confidence where high confidence scores, and within the low confidence CSCD matrix, accurate results may not be given.

Between the low and medium CSCD matrix, there are small percentage changes in confidence between Cloud Storage technologies and conversation tools (32%), desktop application sharing (50%), video conferencing (25%) and shared file repository (48%). The link between Cloud storage and shared file repository is especially vital as although the number of connections for the shared file repository column overall was lower, this change in the number of connections justifies that the text processing method is accurately coding the GDP 2018 data. However, there is a lack of data to display a large number of connections. This could indicate a gap in knowledge for the students in terms of the importance of cloud storage technologies or a lack of experience.

Within the functionality of conversation tools, there are many CSCD requirements that are justified by a lower change in percentages. In particular, the connections between conversation tool and complexity managing the sharing of data (41%), knowledge capture (42%) and overcome boundaries of access (27%) all had a lower number of connections, but a low percentage change that justifies the success of the coding process.

Group dynamic tools functionality had significant low percentage changes between low and medium confidence for feedback mechanisms from stakeholders (48%) and innovative thinking (35%). The connection between group dynamic tools and feedback mechanisms from stakeholders is an important one to highlight as the use of group dynamic tools is used in industry to include the opinions of those outside the primary design team commonly. Students could benefit from this phenomenon by bringing in distributed experts or users to the design process, that is something that commonly does not take place during the GDP.

A key finding was identified between the low and medium confidence CSCD matrix between artefact-mediated communication and desktop application sharing (33%). This is a meaningful connection to highlight that the CSCD matrix recognises the use of artefacts within technologies that support desktop/application sharing technologies such as video conferencing to support CSCD.

Video conference had many critical connections identified between the low and medium confidence CSCD matrix. Feedback from stakeholders (27%), communication (38%), artefact-mediated communication (32%) and commonality (47%) all had low percentages changes in the number of connections. Commonality is a difficult CSCD requirement to quantify due to the soft skills involved. This small percentage change identifies the success in CSCD for identifying connections between the two criteria but highlights more data is required.

Shared file repositories also had many connections between the low and medium confidence CSCD matrix. Critical connections include complexity managing the sharing of data (13%), knowledge capture (50%) and overcoming boundaries of access (19%). The connections with the sharing of data and overcoming boundaries are well justified in the discussions so far. Knowledge capture is one requirement where shared file repositories functionality is required as the technology must enable mechanisms to capture and upload the data easily for successful storage and access to the data.

Between the medium and high confidence CSCD matrix, there are two essential connections that are justified by the percentage difference between the two CSCD matrices. The first is within the technology-functionality matrix between cloud storage and shared file repository (46%). This was explored earlier in the discussion, that supports the analysis of the technology. The second is between artefact-mediated communication and shared file repositories that is also discussed earlier in this section and relates to sharing images to support understanding.

7.4.2 Future work for the GDP class

The outcomes of the CSCD matrix using GDP 2018 class has revealed insights into the students experience within this class. From learning about the student experience in 2018, there can be changes to the curriculum to support students understanding of key concepts and reflection on their own experiences. The outcomes can also be used to demonstrate how the CSCD matrix might be used. Each of the requirements identified impacted the GDP class will be discussed as follows.

It was observed that students did not report on certain key requirements of CSCD for several reasons as discussed. Familiarity with technology is beneficial when using technology. However, there was a lack of reporting on the use of particular familiar technology by students. If there is a surprising feature or functionality, it is more prominent, and then the reflection is unique. When students are preparing their reports, they might prioritise more exciting results with unusual technologies. This could limit the usefulness of the CSCD matrix as the data is not fully representative of the projects. This was somewhat solved by not entirely relying on data from student reports alone, but also interviews with students to ensure sound data capture.

Although a lack of reporting can be somewhat improved, it cannot be solved completely. A lack of reporting will still result in a lower number of connections detected by automated text processing. Unique, new and novel technology will also appear more critical within the CSCD matrix. To further overcome this unbalance, students could be better prepared to notice all connections and their significance through education and opportunities for reflection. This might come in opportunities for further workshops to prepare students for global collaboration projects.

As described in Chapter 5, the survey of experts revealed a ranking of the CSCD requirements from most important to least important. The outcomes from the CSCD matrix, in general, displayed a higher number of connections for the higher-ranked CSCD requirements. This perhaps reflects that student focus on reporting the most important requirements.

This leads to another critical question about the appropriate number of connections. It was displayed that there are noteworthy results because of many reasons; a high number of connections compared to all other results, a high number of connections compared to others within the row/column or a low percentage change between different confidence levels of CSCD matrix. However, these criteria are relevant to the data collected rather than an arbitrary number. One connection is enough to display a connection between two criteria, and this could be just as significant as 200 connections. The systematic automated approach certainly creates an answer and populates the CSCD matrix. However, it is not an answer without an examination of the results.

An example of this can be observed with the polling tools functionality. Low numbers of connections were observed throughout this column. However, this does not mean polling tools were not used, and in fact, they were used successfully by students to justify decision making, and these are the connections recorded.

One downfall of the CSCD matrix that has been highlighted by the outcomes of the GDP 2018 data is that although it produces quantitative knowledge from qualitative data input, the CSCD matrix itself is not a quantitative tool. The CSCD matrix and the auto-population does not produce a one size suits all solutions to CSCD projects. This outcome is as designed. The method leads to an output that enables analysis of the results. The results are then considered with a reflection of the project challenges and the team that will use the software. This produces depth to the outcomes, that could be automated but perhaps not to the nuance required with so many considerations.

The GDP is a suitable representation of a CSCD distributed design projects due to its nature, however, it does not represent all projects and all situations related to CSCD. Students engage in small projects with very little knowledge transfer between teams, in and out of the design team itself and with a requirement for data recall. Then knowledge management is not adequately represented in comparison. Groupware is commonly used within enterprise settings and has additional business functionalities. If students do not require these or have the experience of using them, they will not be reported within the data. Finally, trust is also difficult to model as part of the GDP. Trust is built over time between team members and upon shared experiences. Although this can be artificially encouraged, in lew of the time to build these relationships, teams will not be able to reach the same level of trust.

One observation that encouraged the motivation for this research was the increase in students use of social communication tools and if they can support project communication. Indeed, there are many connection examples that support this idea within the output data. However, these connections were not always where expected. Social communication was highly observed both for social network sites and team management groupware technologies. Video conferencing is one opportunity to encourage more social communication as very little was reported. Video conferencing is also a highly immersive tool that is perhaps underutilised for this purpose.

There were some apparent successes, such as the 208 successful identification between the Collaborative document editor and the shared editor functionality. Furthermore, the connection between group dynamic tools and innovation suggests that it may be better for design teams in the GDP to encourage innovation over technologies such as messengers, video conferencing technology and social network sites. This should be a proposal that makes its way back into the class preparations.

As a final suggestion for the students taking part in future GDP, is that the reflection often follows interactions between students, i.e. human factors, and there is less emphasis on technological interactions. Whilst interactions between team members are essential when considering social factors, and these tend to be in-depth due to their nature. In contrast, reflections on technology and functionality have a more significant potential to impact several users each year and can be more systematically studied.

There were cells populated in the CSCD matrix using GDP 2018 data that did not represent what was expected. One clear example of this is between video conferencing and desktop/application sharing. This technology has this functionality, but the outcomes did not deliver this result. This perhaps suggests that the dictionary was not developed adequately enough to code this particular link. The only other connection that requires further development is the requirement of motivation. There were simply not enough connections within this row, suggesting that the matrix did not function correctly for this CSCD requirement. This is likely due to a mixture of a lack of reporting and a limited dictionary to code successfully.

Considering non-connections where a cell was not populated by any connections, there are many reasons for this. There simply may not be any connection between the CSCD requirements and the technology functionality as the two concepts do not align. A comparison of this can be observed between the conversation tool functionality column and the polling tool functionality column within the low confidence CSCD matrix. Conversation, be it verbal, or text-based is critical to all collaboration. However, polling tools had few connections with many CSCD requirements. This could be simply explained as polling tools are not required to manage data as suggested by the outcomes of the CSCD matrix and will always display a non-result. On the other hand, polling tools demonstrated connections with cooperation and decision making, which was expected for such a tool. This could not be confirmed explicitly without further studies.

Email is a technology that scored very low across its row with technology functionality. It, therefore, cannot be confirmed for sure if these functionalities have no connections or it further study is required. Over time these connections may be built as technology develops. An email programme may come along, which can integrate better social tagging and syndication as these features begin to emerge.

7.5 Reflections on the CSCD matrix as a technology evaluation and selection method

The CSCD matrix was inspired by QFD approaches in the literature to technology evaluation, and goes beyond what can be achieved with a regular QFD, focusing on CSCD as a domain and creating a clear profile of technology that can be used for the task. Building upon the work of others, the requirements of CSCD and the identification of technology functionalities suitable for the evaluation are a unique part of the CSCD matrix that could not be achieved when specific CSCD knowledge is not known within a design team.

A significant part of the reliability of the CSCD matrix and the method developed to populate is its use as a systematic method and a tool. Systematic is not a reference to accuracy or truthfulness but states that if the same activities were to be conducted, the same outcomes would be found. Systematic does not apply to all parts of the CSCD matrix development as it would not be possible, but critical parts had to be completed systematically as discussed as follows. Towards meeting the aim of the project, there needs to be an evaluation of the systematic method developed.

There were two systematic components of the projects being the literature search and the automatic population method of the CSCD matrix. The literature search was conducted methodically and documented within Chapter 4. The structured approach is detailed to repeat the search, and if done so, the same results would be recorded. There should be mention, however, that search engines can change over time, papers they contain can be added or removed, and metadata associated with papers may also change.

The development of the 19 CSCD requirements is based on this literature search and the 220 requirements of CSCD. Indeed, the same papers would have been found within the literature search, and with a liberal approach, the same 220 requirements of CSCD would be found following the rule on explicit statements. However, the development of the 19 CSCD statements was influenced by the opinions of experts. This part of the process cannot be considered systematic because if the same experts were asked to comment on the same principles, their opinions might have changed, becoming very different.

The population of the CSCD matrix is conducted systematically because of the automated text processing influenced by the dictionaries. The dictionaries are not systematic. Even if the three coders who created the dictionaries were asked to conduct the task again, it is a possibility that their opinions may change the results of the dictionaries.

Once established as dictionaries, the method of populating the CSCD matrix is systematic. It uses the same word in the same categories applying the same scoring system. As an automated method, it is difficult to argue as it will produce the same results each time the software and coding is executed.

One consideration that impacts both systematic areas of the research is temporal. If the systematic search or the coding were conducted at different times, the results may be different. Related to this is the time period of the research.

The CSCD matrix developed with data of the GDP is only relevant to the data that has come before. If the behaviours with the class were to change, or technology were to change, then, the CSCD matrix would not be relevant. This is the reason why the method of the development of the CSCD matrix is the contribution to knowledge and not the matrix itself, as a tool. To update the CSCD matrix, the data should feedback into further development of dictionaries that would update from the use of colloquial text and new words.

To continue development as required, it is crucial to establish a versioning control for the CSCD matrix. The dictionaries and coding produced within this document should be considered V1_RB_GDP18 (Version 1 produced by Ross Brisco using the GDP 2018 data), and subsequent updates should be considered version updates or may be augmented for alternative purposes. When a new version of the CSCD matric using the appropriate method is produced, the version that it is based upon should also be referenced for tracking of changes e.g. V2_RB_GDP19 based upon V1_RB_GDP18.

Considering the methodological approach, the systematic integrity supports the updating of the knowledge within the CSCD matrix. If significant changes in technology use were to occur, such as the invention of Web 2.0 technologies that contributed towards the motivation for the conduct of this research project, the parts of the CSCD matrix could be updated to address these new challenges within the same familiar package using the method established within this thesis.

It is essential to discuss that the practical outcomes of this thesis are not generalisable to all collaborative design scenarios, including use within industry, or for other applications such as an analysis technique for cooperation. However, the framework for the processing and understanding of data has been proven.

Considering how the research in this thesis has been conducted and how it may be used in the future, there are many similarities in the approach of Gopsill (2014), who utilised email communication from a student engineering design project and applied a text analysis technique. The benefits of the systematic approach within Gopsill's work justifies the work within this thesis as a development approach, e.g. using students to test a method for later implementation in industry. There do have to be significant changes for this to occur. However, the same systematic method that has been proven can be applied again. The same methods, that are systematic, have worked and could work again for other scenarios.

The systematic method created is a first of its kind in the method to assemble the knowledge, but also in the contribution to knowledge within the context of CSCD. The systematic literature search process is well established. However, the knowledge created of the requirements of CSCD is a new contribution to knowledge developed using the systematic search.

The CSCD matrix contains a minimum of 209 relationships between one technology, the technical functionalities and the CSCD requirements, that supports the profiling of a single technology. This number of relationships for consideration by a person or team of people would take several hours to understand, discuss and populate the matrix with rationale. To be educated on the CSCD requirements enough to have a meaningful discussion would also take considerable time. If multiple technologies are to be considered, the process grows linearly and with cognitive fatigue. The production of the automated text processing and automated population of the CSCD matrix means that the time to produce this completed matrix is reduced, and the experts required to analyse the results is reduced.

The people required to complete the CSCD matrix, if it were not created from published literature and expert opinions, would be those who know the company in-depth, with a good knowledge of the technologies and who have good knowledge of theories of technology functionality and supporting CSCD requirements. Within a design team, it would be possible to find experts in the company, but it is less likely to find someone with knowledge of available technologies, functionalities of those technologies and the requirements of CSCD. The CSCD matrix method is based on existing academic peer-reviewed knowledge, that supports the processing of technologies with ease and with less input from the design team in terms of interpreting and populating the results.

The automated technique does not detract from the discussion and analysis of the results. It encourages analysis of the results to test and try new technologies. It encourages a sentiment that the status quo may not be perfect, and other technologies may exist that support the team's collaboration better. Then with automated processing, this can be tested and changed. It also supports the notion that a one size fits all technology solution may not be best for all scenarios and for all teams. There needs to be some contemplation into the technologies that would be proposed for processing by the CSCD matrix and an understanding of different outcomes that the matrix produces. It is, in essence, a decision support tool but does not make the decision academically and independently.

Using the GDP 2018 data to provide a practical example of the method, the objectives of the project can also be considered.

A CSCD matrix was successfully created enabling the method of technology evaluation and selection. The method compares CSCD requirements against technology functionality to support the identification of suitable technology. The CSCD matrix is presented in Chapter 6.1. Workshops and an online course were created that use the CSCD matrix to teach students about technology selection and deliver a systematic way to profile technologies and discuss them within their teams.

The second objective was to create an automated and systematic evaluation of technologies that support CSCD. Chapter 6.3 – 6.5 documents such a process that automates the coding of sentences and automates the population of the CSCD matrix. The decisions made to build this automation are fully documented, meaning the process can be replicated and updated if required. The process is systematic due to its repeatability and the same outcomes of the process would be generated each time.

The final objective is to evaluate the use of the CSCD matrix with engineering design teams in an educational environment. Towards this objective, the experience of using the CSCD matrix within an education environment is discussed with feedback from students based on their experience and experts are consulted on the usefulness of the CSCD matrix within education within Chapter 8.

In addition to the aim of the research, the research question and sub-questions must also be evaluated with regards to the project as a whole and the sections. This project answered the first question: RQ1. Can a systematic automated method be established to support the selection of appropriate technologies that for CSCD in engineering design team projects?

Not only was a method created, but it was tested with real project data in Chapter 7, and it was used in a real-world educational environment (Chapter 8).

The project established the nature of the relationship between technologies that support CSCD and engineering design work. RQ1.4 What is the nature of the relationship between technologies that support CSCD, the functionalities of those technologies and the requirements of CSCD? Through logical investigation into the connections and the use of the E2 design activity model with CSCD. This was created in support of RQ1.1 Which technologies are used to support CSCD?, RQ1.2 What technology functionalities are used to support CSCD? and RQ1.3 What are the requirements to support CSCD? These theory-building steps are a contribution to knowledge established from peer-reviewed literature and reviewed by experts in CSCD.

A method for a reliable and repeatable population of the CSCD matrix is described in Chapter 6. The method is automated based on a set of principles that can be analysed and updated if required.

To understand how the matrix can help to identify the best technologies, a study was completed using GDP 2018 data detailed in Chapter 6 to answer RQ1.5 How can such a method be utilised dependably? The method was successful in creating multiple confidence levels of the CSCD matrix which can be used to analyse the GDP 2018 and inform future technology selections for the class. The success of this method is discussed in Chapter 8 which support RQ1.6 How successful can such a method be in supporting engineering design teams to identify the appropriate technologies?

Considering this discussion to establish the success of the project, there has been an identification of future work. To better generalise the method for other contexts a future study should be considered to establish requirements, functionalities and technologies more generally and to build a method for more generalised data to be considered by the CSCD matrix. Towards the aim and its focus on CSCD the research questions have been answered, and the aim and objectives complete.

In answering the above research question, the CSCD matrix has demonstrated a systematic and robust tool for many purposes. At a strategic level, the CSCD matrix acts as a self-assessment tool enabling the positioning of technology toolkits by profiling within a broader context, such as a class or organisation. On a tactical level, the CSCD matrix is a design space tool enabling justification for decisions made on individual technology use. Moreover, on an operational level, the CSCD matrix acts as an assessment tool enabling profiling and agility when technology does not meet the requirements.

7.6 Summary

In this chapter, the automated text processing method is validated and the method for evaluation and selection is demonstrated using data from the GDP 2018. Data was prepared and processed through the automated text processing method to output the connections between criteria of the matrices of the CSCD matrix and this data is mapped onto the CSCD matrix. The result is a profile of the GDP 2018, the technology used, the functionality available and the requirements satisfied at different levels of confidence.

Three profiles were created with low, medium and high confidence. The results are presented in Figure 7-1, Figure 7-2 and Figure 7-4. These diagrams can be used to understand which technologies have which requirements, and which functionalities satisfy which requirements of CSCD. This is achieved by displaying the number of reported connections identified in the GDP data meaning there is confidence in the existence of this connection. The percentage change from low to medium and from medium to high confidence is displayed as Figure 7-3 and Figure 7-5. This is conducted as a meta-analysis of the work to determine the usefulness of the confidence levels and the percentage change between levels. Figure 7-6 displays the non-connections that identify technologies that lack functionality, or functionality that lacks a connection with a requirement of CSCD. This outcome may identify a need to add a new technology to satisfy the requirements of CSCD.

Reflections on the outcomes of this data is discussed. Firstly, the data was successfully mapped using the method as designed. The technology evaluation and selection technique is functional. This analysis enables an understanding of how the technologies in the GDP were used and how this use contributed towards the completion of CSCD projects. Each technology and requirement is discussed with key factors highlights. The differences between the levels of the CSCD matrix is also discussed with key differences detailed. The analysis revealed that the low medium and high level of abstraction is sufficient to determine different levels of confidence. However, the high confidence may also have nuances where the confidence is less or more within this representation. This can be displayed from large changes in connection between medium and high confidence representing that there was a lack of data or perhaps a lack of synonyms.

The use of the GDP 2018 data has revealed that this method is suitable for the continual development of a global projects class within an educational environment. The data from the 2018 edition of the class can be used to inform technology selection for the 2019 edition and beyond. It might also highlight areas for future technology development to fill requirements that are currently lacking. In allowing for the comparison of communication, cooperation and coordination, it is clear that communication contributes most to collaborative practice through the identification of conversation tools functionality towards the requirements of CSCD in the GDP 2018. This supports authors focus on communication over the years, however, highlights other important aspects of collaboration that remain less investigated. Future investigations and limitations of the insights into the GDP are further discussed.

8 EDUCATIONAL CONTRIBUTION - AN ONLINE COURSE IN CSCD

In this chapter, the development of workshops on the use of the CSCD matrix are described. The requirement for such workshops is discussed and the potential impact for CSCD classes globally. Having created delivered and developed an in-situ workshop over many years, an online short course was developed allowing all student no matter where physically located to be involved. The focus of the online short course was to deliver the required understanding of collaboration issues, to be able to use the CSCD matrix. Future development is discussed with educational modules for industry.

8.1 Future impact for an educational environment

The development of the CSCD matrix was closely linked with the GDP class and the creation of workshops to educate students on CSCD better. These were conducted with students of the GDP from 2016 to 2018, and an online version of the workshop replaced the in-situ workshops in 2019 and 2020. In supporting the creation of these workshops, the CSCD matrix was used to produce toolkits based upon the GDP data 2018.

To support future GDP classes, CSCD matrices were produced to provide an example of the impact this work can have and how to use the outcomes of the research in a practical way. Mamo et al. (2015) suggested a toolkit of engineering design tools for multidisciplinary distributed student teams. This toolkit has been modelled in a medium confidence CSCD matrix displayed in Figure 8-1. The matrix suggests there is a lack of audio conferencing, social tagging systems, search engines and syndication tools.

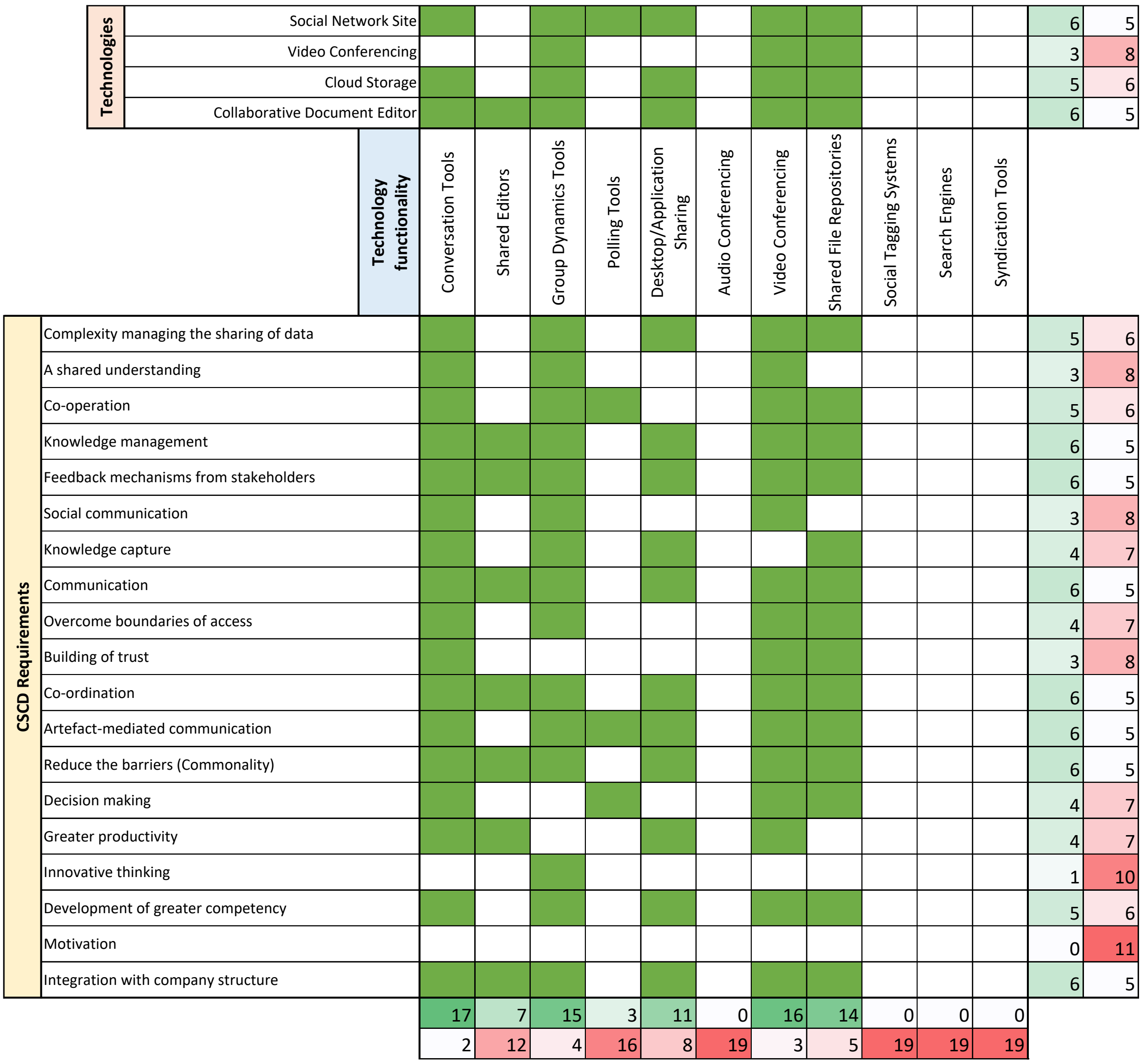


Figure 8-1: Toolkit for engineering design suggested by Mamo et al. (2015)

An observation of student's technology use over time, as discussed in Chapter 2, was the change from social network sites to team management groupware as it raised in popularity around 2017 and 2018. Now, tools such as Microsoft teams can offer this functionality. A toolkit is produced that displays the changes in the CSCD matrix if a social network site were to be replaced with a group management tool. This is displayed as Figure 8-2.

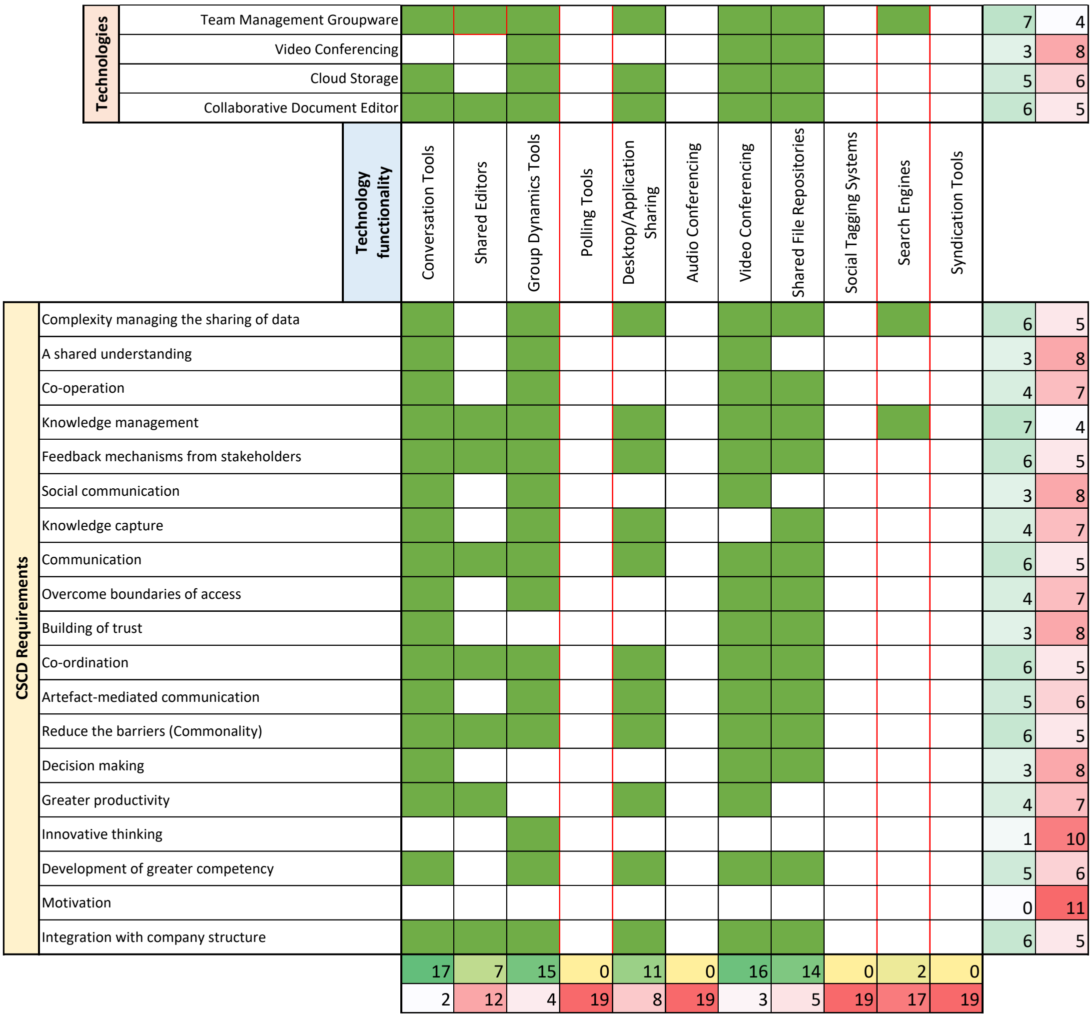


Figure 8-2: Toolkit suggested by Mamo et al. (2015) with SNS replaced with TMG

This scenario represents where a new technology is identified, and the team are considering the integration of this new technology to replace an outgoing technology.

When this is swapped into the toolkit as a replacement for social network sites, there are some key differences. The toolkit would lose the functionality for polling tools and would gain search functionality. There may also be a consideration by a team for overlapping functionalities which is displayed in this example where team management groupware shares the functionality of shared editor with collaborative document editor. This would suggest that a collaborative document editor may not be required in addition to team management groupware as this functionality is inherent to the technology.

This scenario may also be compared with individual technologies rather than toolkits as displayed in Figure 8-3. This comparison may be useful when the full details of the toolkit are unknown as it does not provide any knowledge of overlapping functionalities.

The final use of the CSCD matrix is to identify the functionality requirements of new technologies. The matrix displays a blank cell where a technology, functionality and requirement are not identified. This could be a useful insight for teams to identify deficits in their abilities or for technology creators to design novel abilities of software.

8.1.1 The significance of the outcomes for an educational environment

The method developed to create and populate the CSCD matrix fills the gap as identified within the GDP and the wider engineering design community. The creation of this evaluation method is novel for an educational environment. The method is systematic in nature but also results in a systematic tool. There are currently many available technologies. However, there is a lack of knowledge on the requirements of CSCD projects and a way to link these requirements to the technology abilities. The CSCD matrix is one tool that enables this to happen and using verification of the methodology and evaluation of the outcomes, the CSCD matrix can be demonstrated as a valuable tool. Within an educational environment, this can be proven for the GDP and could be extended to other globally distributed CSCD projects with a partnership.

For education, the CSCD requirements, as identified, are a new contribution to knowledge. Although they may not represent a completed list, they are complete within the systematic approach conducted using a reliable source, i.e. published peer-reviewed literature. Students can begin to benefit from the CSCD requirements by learning about them. The 19 requirements could act as lecture outcomes, discussion points within workshops or as a reflection checklist.

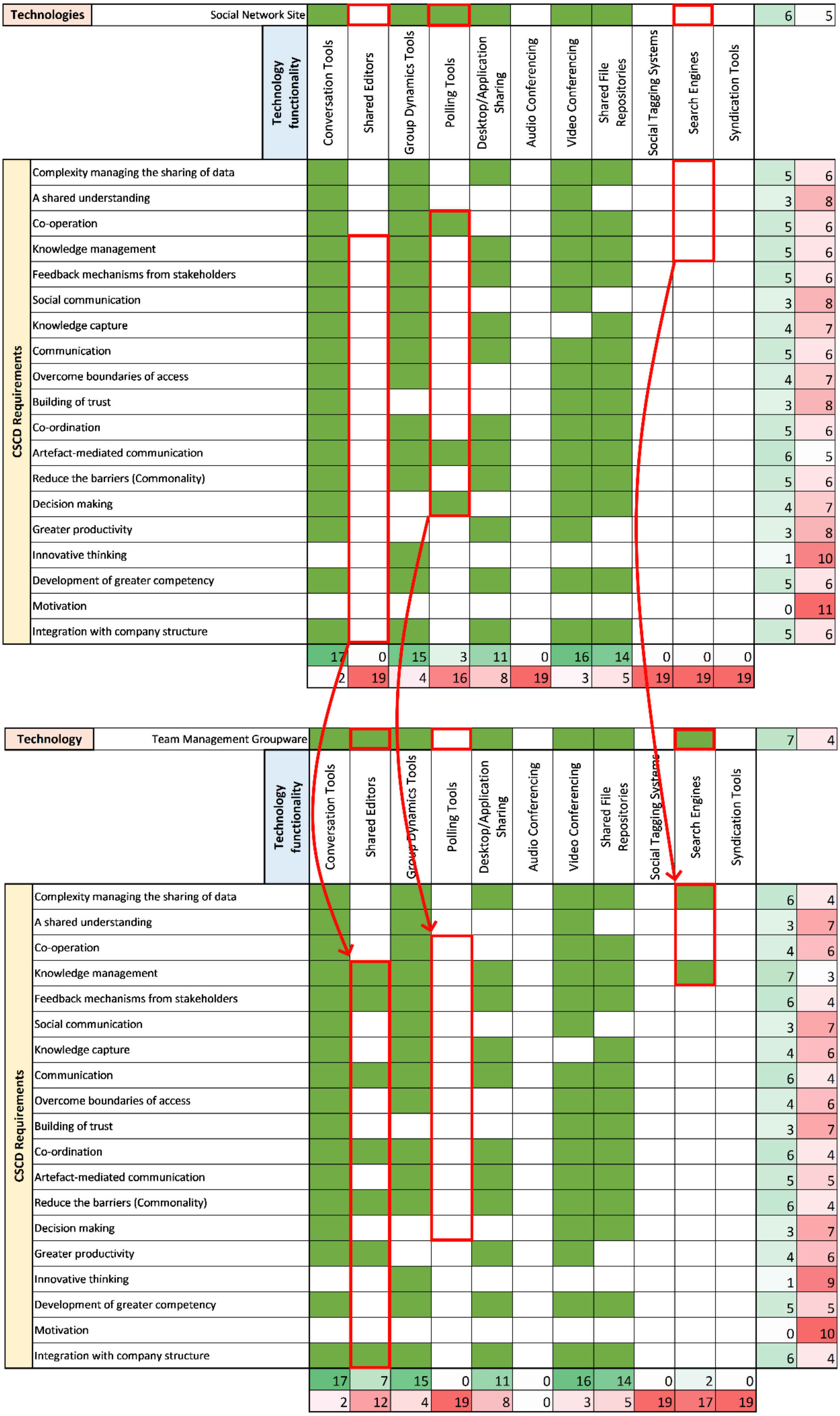


Figure 8-3: Comparison of individual technologies in a matrix

Change is easier to observe within the GDP compared to within enterprise as for large scale changes to take place in technology use in society, there must be unprecedented challenges to overcome. This was observed in the adoption of video conferencing technologies and the increase in online teaching as a result of the Coronavirus pandemic (COVID-19) in the first half of 2020. However, from year to year of the GDP, changes are frequent. Different technologies are popular, and so technologies change. Different types of students bring technologies from their personal lives to try and test. The CSCD matrix then acts as a justification for the technologies they are exploring. If changes are observed, the CSCD matrix can be used to evaluate new technologies and compare. This could be between year groups or throughout the year. This could even be conducted by different team members, as the criteria remain the same.

As a tool, the CSCD matrix is taught in two parts, how to use the tool, i.e. input and process data, and the knowledge that builds the tool i.e. collaboration. In understanding the tool, the possibilities for its use become significantly increased. The tool has been demonstrated to successfully profile data from a collection of technologies, i.e. the technologies a class might use. It could be used in a similar way to profile individual technologies for comparison. However, these stem from technology used to find out if they meet requirements. Just as quickly, the entire system could be reversed where the CSCD requirements are the primary input of data, and the technology is mapped after. In doing so, the opportunity to determine which technologies support which requirements becomes possible; for example, a team could identify a design technique they would like to use, such as a weighting and rating matrix. They can identify which requirements support weighting and rating. The matrix can then lead designers through technology functionality to identify the best technology or a mixture of technology that satisfies the requirements.

The other level discussed above, AKA the knowledge which builds the tool, enables development for alternative purposes. If another type of project arises, such as a blended environment of online and offline team members, or a collocated environment, then the knowledge that builds the CSCD matrix can be altered to best suit these situations. With a little development, a more extensive range of students could benefit from the tool. Furthermore, it does not stop with design teams or even engineers. The tool can be proven in a range of scenarios. This will not happen without stimulation, perhaps in the creation of a database of tool types and continuous development and evaluation for different scenarios.

Students have been through a period of change with these new technologies entering their lives. Moreover, future generations will experience the same change with future technologies. There is a constant cycle of new ideas being tested in the classroom, that may make their way into enterprise tools. Students who have experienced the rapid change of technology will expect to be able to use some of these tools in industry when they graduate. This would be of benefit for employers to promote as students have been building skills in the use of these novel technologies, and these skills can promote effectiveness and efficiency. This is observed in the GDP as students who are told they must use a particular technology (In the GDP 2016 and 2017 students are asked to use Box for storing project documentation in the cloud) do not engage with it well and do not display enthusiasm for the software. However, when they discover a technology within their teams and agree to use it, they are very enthusiastic about its functionalities and how this would support the teams work.

It is also not unreasonable to assume that messengers, social network sites and social groupware become a fundamental skill in the eyes of an employer along with Microsoft Office use and soft skills. Students then need the ability to practice these skills in a digital environment that University can offer.

The development of the CSCD matrix creates opportunities for better learning experiences. As discussed, students can be educated on the impact of technology selection on the success of their projects by meeting the CSCD requirements. Also, educators can plan technology use within their classes using the method, at a higher level, learning technologists can systematically evaluate different technologies towards criteria in a systematic way for an entire department, faculty, school, or University, and there is a potential to create learning environments for an enterprise audience based on reflection of the success of workshop development within education plus additional considerations for enterprise.

As the research developed, preliminary investigations took place and workshops were conducted as described in Chapter 2. The outcomes of these workshops were collected and published as Brisco et al. (2016) for outcomes from the GDP 2015 workshops, Brisco et al. (2017) for outcomes from the GDP 2016 and Brisco et al. (2018) for outcomes of the GDP 2018 workshops. The outcomes include the identification of gaps in students' knowledge and observations of students use of technology

Following the GDP 2015, as discussed in Chapter 2.2, there was a need for future students to reduce the number of communication technologies used. The CSCD matrix can highlight overlapping functionalities enabling for the reduction in the total number of technologies. Students were also encouraged to ensure the correct technologies are used to support successful collaboration at the right times, e.g., cloud storage is used for document storage and not messengers, even if the functionality is offered. The CSCD matrix can enable an identification of where functionalities are shared, and misuse of technologies could take place. Finally in 2015, the GDP studies identified the gaps that technology cannot fill, and students were encouraged to create protocols to overcome these. The CSCD matrix supports the identification of gaps that current technologies or created toolkits cannot fill.

Students identified in the GDP 2016, as discussed in chapter 2.1, that they believed they were better suited to understand novel technologies than the teaching staff of the class. This was clarified as students believe they have a greater awareness of new and novel technologies than the staff teaching the GDP. This sentiment inspired the CSCD matrix in its use developed within this thesis as a tool for students use facilitated by staff from sequential years of the project. This empowers student’s decision making and puts the responsibility of their decision on their team, with education on collaboration from more experienced teaching staff. The CSCD matrix enables this however there was a requirement for workshops each year to educate students on collaboration and the use of the matrix. The CSCD matrix is not a standalone tool which justifies the research and educational contribution to knowledge.

In the GDP 2017, as discussed in Chapter 2.3, there is a clarification within the discussion that with a shared platform comes opportunities for greater collaboration. However, team members of the GDP tend to generate concepts in smaller working groups and then come together to share outcomes. Using the CSCD matrix to consider the requirements of CSCD and identifying where technologies have no connection highlights the importance of all aspects of the requirements of CSCD. The CSCD matrix highlights the importance of a shared platform for awareness and syndication of all.

Students are torn between always being available for quick questions of team members and having personal time. This might go some way to explaining why the syndication and social tagging system tools had little connections overall on the CSCD matrix using GDP 2018 data as they contribute towards a productive project but perhaps not a happy one for students who are always being notified. Technology companies are becoming aware of this with functionality to limit notifications on mobile devices and separate social network sites to segregate professional and personal notifications.

An important aspect of the technology evaluation and selection method developed is the systematic population of the matrix using established rules. This provides justification for students to select technology beyond familiarity. As students spend exploratory time with technologies at the start of the project, they socialise and build team familiarity before the design project begins. Again, beyond the research contribution, the educational contribution has change the way the GDP is conducted by offering greater awareness to students of the importance of CSCD decision making in a systematic way, and how their decisions impact their projects.

8.1.2 Development of workshops to support students learning in CSCD

Alongside the development of the CSCD matrix, workshops took place with students to educate them on global collaboration.

Following the first GDP in 2015, it was identified that there was a need to support students' identification of the best technology to use as part of the class, that could be based on the experiences of the previous classes, but could also be updatable with students' experiences and knowledge of new technologies. In the 2016, 2017 and 2018 academic sessions, students were asked to take part in an in situ CSCD workshop to prepare them for the projects. This took place before team members were assigned to a group, and before the project work began. The workshops were also delivered to students of the GS at Loughborough University Design School in 2016 and 2017.

The workshops included an introductory lecture on what is CSCD, followed by three questions designed to challenge the students to think about their own collaborative practices, sharing of outcomes from each of the teams back to the larger workshop group, and concluding with a closing presentation.

The workshops introduced students to CSCD and models of collaboration from the published research, i.e. the 3C model, that first appeared in the book Groupware by Johansen (1988). The workshops were designed to highlight recent developments in the field both in research and in practice, such as new technologies, the outcomes of other CSCD projects or the trends over the years. During the workshops, the importance of reflecting on decisions made in selecting the right technology, tools and techniques to facilitate the design process were emphasised. Published research was used to support the knowledge conveyed, including Evans et al. (2013), Bohemia & Ghassan (2012), Gopsill (2014) and Brisco et al. (2016).

Following the introductory lecture, three questions were proposed to the students:

- What are the challenges of supporting collaboration during the design process?
- Which functionality of technology can be used to overcome these challenges?
- Which guidelines would you create to advise future distributed design engineers?

Students were encouraged to identify a minimum of three challenges, three functionalities and three guidelines. Students worked in teams of four to six to answer these questions. Teams were asked to present their outcomes from the three questions to all participants of the workshops.

The closing presentation intended to fill any gaps that the students may not have explored in their teams by presenting best practices as identified in the literature, including the recommendations displayed in Figure 8-4 originating from the initial literature search review and categorisation (Chapters 4 & 5).

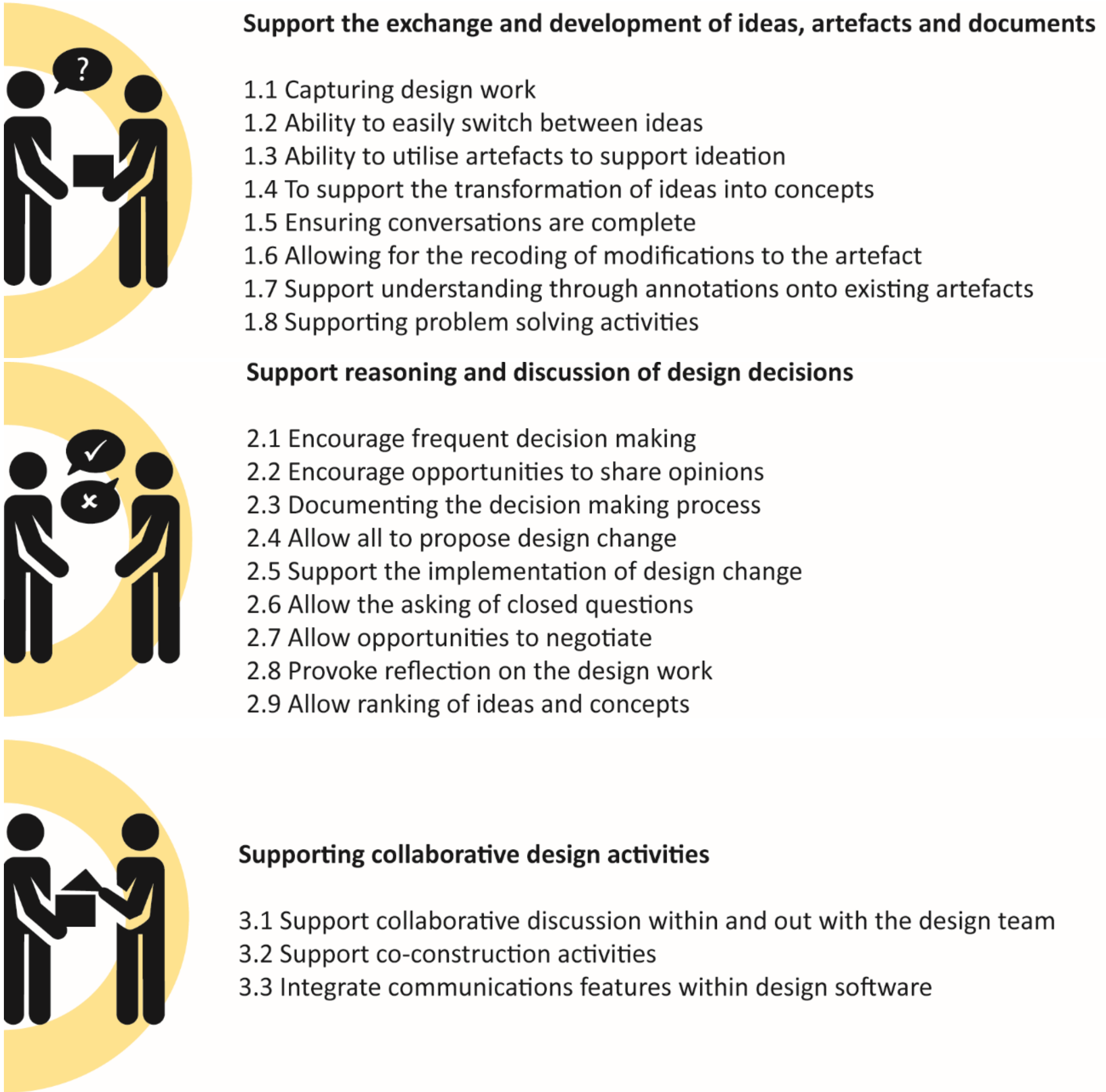


Figure 8-4: The CSCD requirements reformatted for student workshops

Over the years, the workshop activities did not change, but the content of the introduction and conclusion presentations were updated iteratively based on the outcomes of the previous workshops, new literature being published on the topic or questions students had following the workshops.

As the workshops developed, further issues within CSCD teamwork were added and explored with students Figure 8-5. Many of the updates from literature came from students reflections on globally distributed classes such as Integrated Product Development International Summer School (IPDISS) (Lippert et al. 2017; Asadi et al. 2017), The European Global Product Realisation (EGPR) (Vukasinovic et al. 2017; Cristoloveanu et al. 2016) and The Global Studio (Hong et al. 2018).

The importance of CSCD theories in building successful teams and theories of design practice was added to contextualise the importance of the workshops to the student attendees. Models of collaboration were introducing to students with examples of Globally distributed projects and how different models support different team structures.

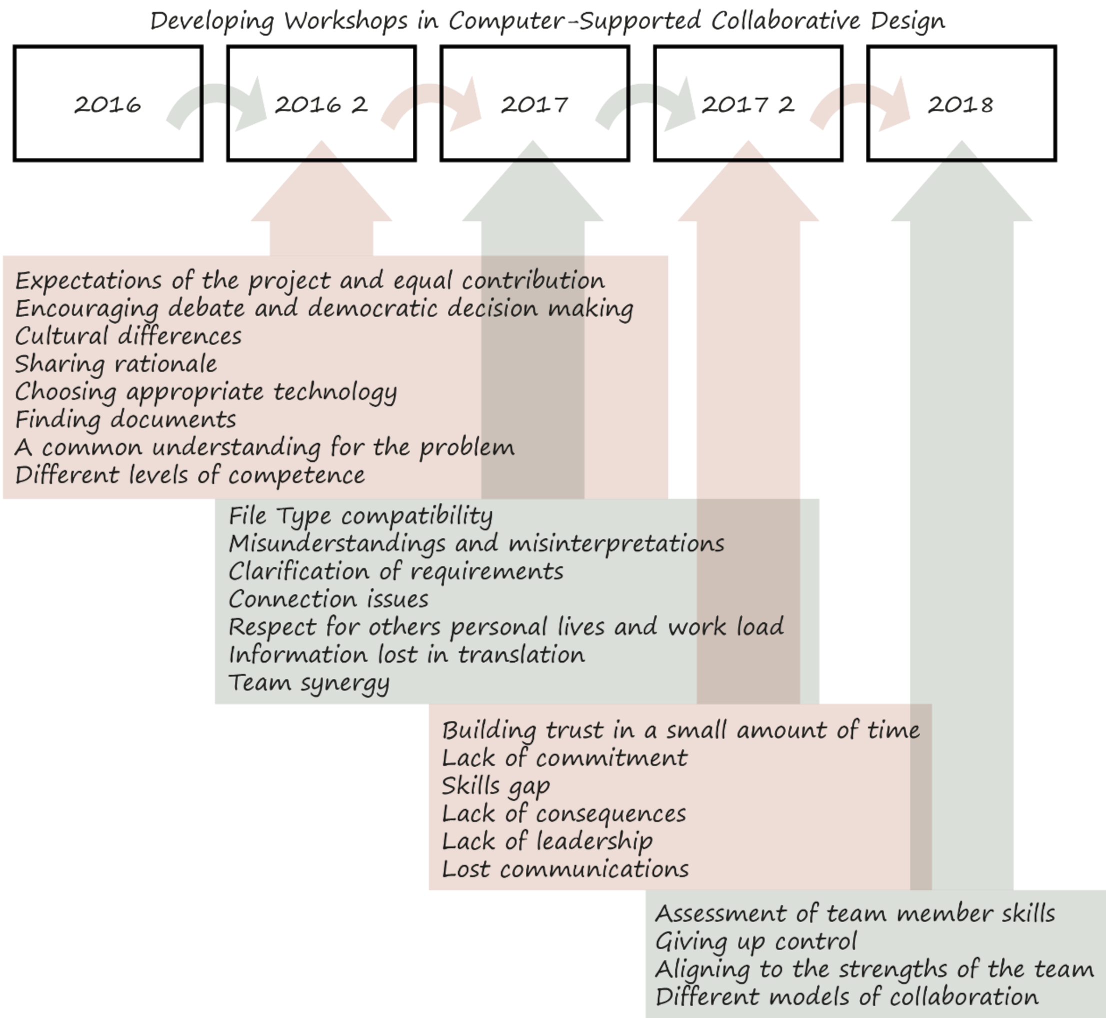


Figure 8-5: Knowledge added to the workshops over time

Following each workshop, activity recommendations were suggested to students. Following the 2018 workshop, these had developed into the following:

1. Use an evaluation method to select the best technologies and not based on popularity.
2. Consider how collaboration challenges might be overcome ahead of the project.
3. Be critical of technologies and practices, test and change them as required.
4. Choose a limited number of technologies to keep communication simple.
5. Support all communication methods required and for all devices used.
6. Support for required functionalities throughout the project.

7. Awareness of other team members works to demonstrate competency and trust.
8. Team protocols for storing and sharing knowledge need to be agreed.
9. Team expectation needs to be discussed and agreed.
10. Team roles should be assigned to ensure the recording of data and regular communications.

The CSCD matrix was first included in the 2018 workshop, with the majority of students in a follow-up questionnaire agreeing that the workshop was highly relevant (18 out of 28 students) and the reminder that it was somewhat relevant (10 out of 28 students). The other two options were somewhat irrelevant or totally irrelevant. All student responded that the workshop contributed positively towards their understanding of CSCD. The results for the understanding of the CSCD matrix was mixed Figure 8-6. Although the majority of students could use the CSCD matrix with little or no guidance 64%, a significant proportion 36%, still said they would struggle to use it and therefore do not understand the CSCD matrix.

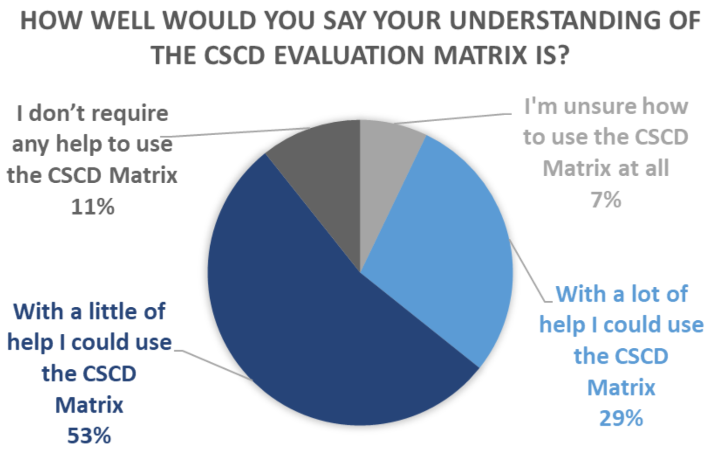


Figure 8-6: Feedback on students understanding of the CSCD matrix following the 2018 workshop

Within a feedback box students shared reasons for the lack of understanding which were need for further clarity "matrix works but is somewhat hard to understand", particularly in the method of the CSCD matrix creation "The purpose of the numbers on the sides of the matrix and how they are derived is unclear". Upon reflection, there was too much of a jump from requirements to the CSCD matrix, and the creation of the matrix had to be conveyed to students for them to understand how to utilise it best. HoQ is a familiar tool to students, yet the CSCD matrix has developed too far away from these ideas that it is no longer recognisable.

Following the GDP 2018 a further survey was distributed, which asked if students used the CSCD matrix and how. The following responses were the ways in which the matrix was used:

- To evaluate technologies at the start of the project.
- To identify the most appropriate technologies.
- To overcome barriers when challenges arose due to technology use.
- To ensure that the correct tools are utilised throughout the project.
- As a supportive tool to help the team discuss the available technologies.

There were many benefits observed in the workshops. The outcomes of discussions with the students identified problems that might impact CSCD education. Project-based learning is a well-established method of teaching, especially in building soft skills, and there appears to be a gap in the publication of reflections on the classroom to be shared and implemented into future classes. This type of collaboration would improve knowledge of the requirements of CSCD for all students to benefit. The approach of these workshops, in particular, is to give students state-of-the-art information by reflecting on issues of the previous GDP year but also other related classes. Students can then decide to engage and implement practices as they determine appropriate, but they are at least aware and prepared.

As students use the CSCD matrix to discuss implications for their projects, a student can apply their knowledge of technologies they are familiar with, functionalities they are familiar with and knowledge of the CSCD requirements. Students act as both the learner and the expert. This empowers the students to take responsibility for their learning experience to implement informed decision and creating protocols of working.

One unintended outcome was the student’s reflection on their own performance towards the team’s goals. Students of the GDP struggle to make comments on their own behaviours, but perhaps the CSCD matrix is establishing a baseline in terms of the requirements of technology, and the student have been able to understand the human aspect in technology use. Critical analysis of one's self is essential for reflection and improvement for future projects.

Upon the success of the workshops, a developmental plan was put in place to establish the next steps for an education program. The first was to make the workshops available to all students of the GDP to benefit all. To facilitate access, the workshops would be in the same format as the students are working. As these types of modules are held online distributed, the workshops should also move to this format. An online course in successful CSCD was envisioned based on the workshops. With successful implementation, there is an opportunity to expand to other sets of students, e.g. collocated using technology, engineering faculty students, other distributed courses etc. And finally, there is an opportunity to develop the workshops for an enterprise audience to gain an understanding of the benefits of this tool within the industry.

8.1.3 Development of an online short course in CSCD

The workshops enabled students of the GDP located at the University of Strathclyde to learn about CSCD and engage in workshops to further their understanding. The next steps from this were to allow the other students located at other University to also engage in this learning experience. There was also an opportunity to develop the course to support other aspects of distributed learning, including broader discussions facilitated by a learning management system (LMS) and icebreakers for all participants of the GDP rather than only between team members.

An online short course in CSCD was envisioned, that conveyed the information from the workshops, the CSCD matrix to facilitate teams discussions on technology selection and additional distributed learning features to encourage global collaboration and development of skills that support distributed CSCD.

As the course was to be conducted between institutions, and external LMS was investigated. While it would be possible to include external students to the Strathclyde LMS, and this was difficult to administrate. An external LMS enabled full control by the course administrator and the ability to quickly scale to include other global design courses or augmented courses for other contexts. This was allowed by the institution as the short online course developed would be voluntary for all students if they wished to participate and external from the GDP class.

The short online course would consist of three lessons delivered over one week. This was to encourage reflection between lessons and the time for students to engage in additional activities such as discussion forums, building a connection between students. To ensure a comprehensive learning experience, Salmon (2013) five-stage model was employed to ensure that the online course to appropriate standards.

1. Students were welcomed and encouraged through introductory videos.
2. Small online introductory tasks helped to familiarise students with technology.

3. A demonstration of the course content explained how to engage and find information.
4. Lectures included with the course had knowledge-building activities.
5. Discussion and response were facilitated.

Many LMS were investigated, and eventually, NEO LMS (neolms.com) was selected for practical reasons. The web platform allowed students to sign up on their own. Engage at their own time and had the features and functionality required to build and administrate the lessons. Three lessons were developed and were formatted as follows:

1. An Introduction to CSCD

In the first lesson, students are encouraged to discover different technologies that may support their engagement in global collaboration.

- Introduction to the features and functionality of NEO through self-exploration (Introduce yourself activity).
- Introduction to CSCD, typical CSCD technologies, their use and importance for education and enterprise applications.
- Posing questions about the use of CSCD in global design.
- Question “What are the challenges you may face during the project?”
- Link to ID cards for good communication (Evans et al. 2013).

2. Collaboration Models

In the second lesson, students are introduced to models of collaboration and are asked to reflect on successful collaboration endeavours.

- Models of Collaboration.
- What is Collaboration vs Cooperation, Communication, Coordination?
- Examples of CSCD projects.
- Question “Which collaboration model might you use during the Global Design Projects and why?”

3. The CSCD matrix

In the final lesson, students are introduced to a matrix that supports technology selection for global collaboration projects.

- Introduction to the requirements of CSCD.
- Introduction to the functionalities of technologies that support CSCD.
- Introduction to the CSCD matrix tool for technology selection.
- Best practices for global design.
- Feedback on the course.

It was recommended that students engage in the first lesson on a Monday, the second lesson on a Wednesday and the third and final lesson on a Friday. Each lesson took approximately 20 minutes to complete making the course 1 hour long. Students can work in their own time and take longer if they wish. Screenshots from the course are included in Figure 8-7 Figure 8-8 Figure 8-9 and Figure 8-10.

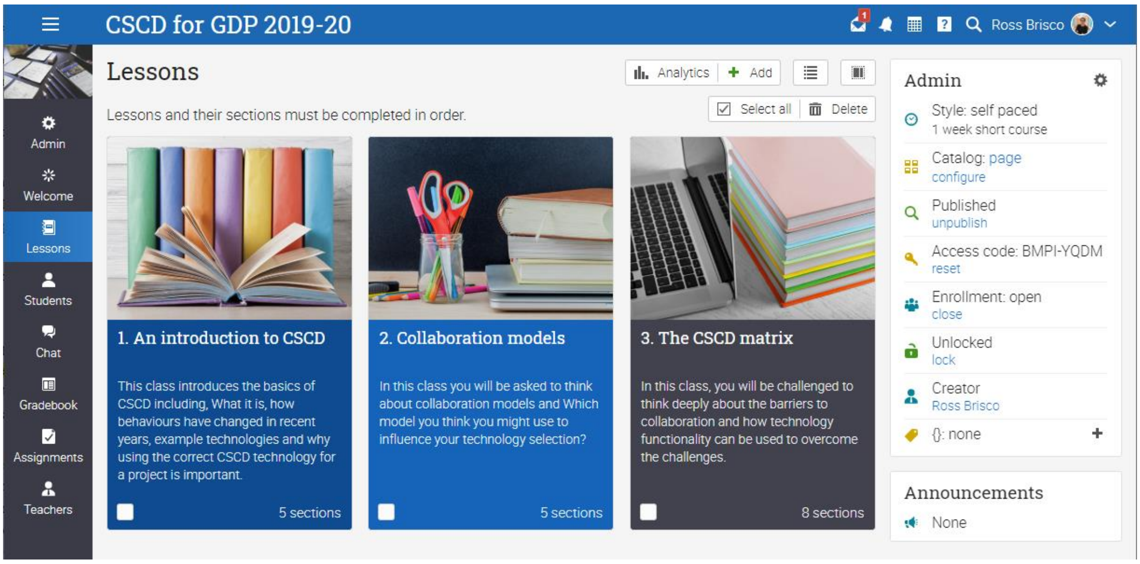


Figure 8-7: The welcome page on NEO LMS and connections to the three lessons

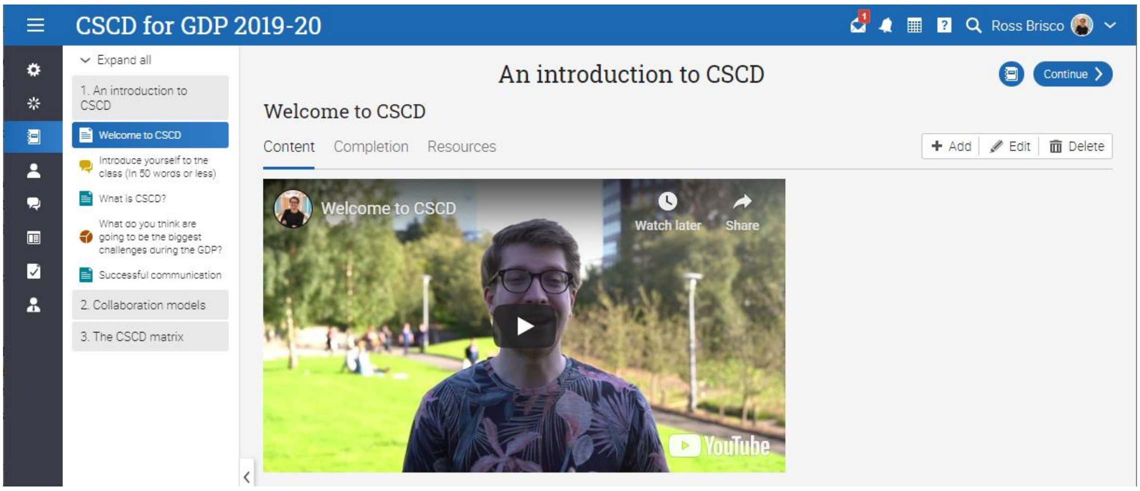


Figure 8-8: The first video introduction for the first lesson

To support reflection, students are encouraged to revisit the previous lessons to recap and read comments from other students included in discussion forums. They are also asked to comment on any discussion posts that they find interesting. A mixture of video and text was used based on the content of the lesson. A test was used when simple diagrams might need study and focus, whereas video was used to build a sense of presence and connection with the students. Text lessons were useful to convey additional information such as websites, connections to publications, connections to external videos or animations of processes. To test knowledge and encourage reflection, students were challenged to think of answers to questions such as "Which functionalities of technologies were important to overcome challenges in global collaboration?" Students created their comments and then engaged in other answers by reading and responding.

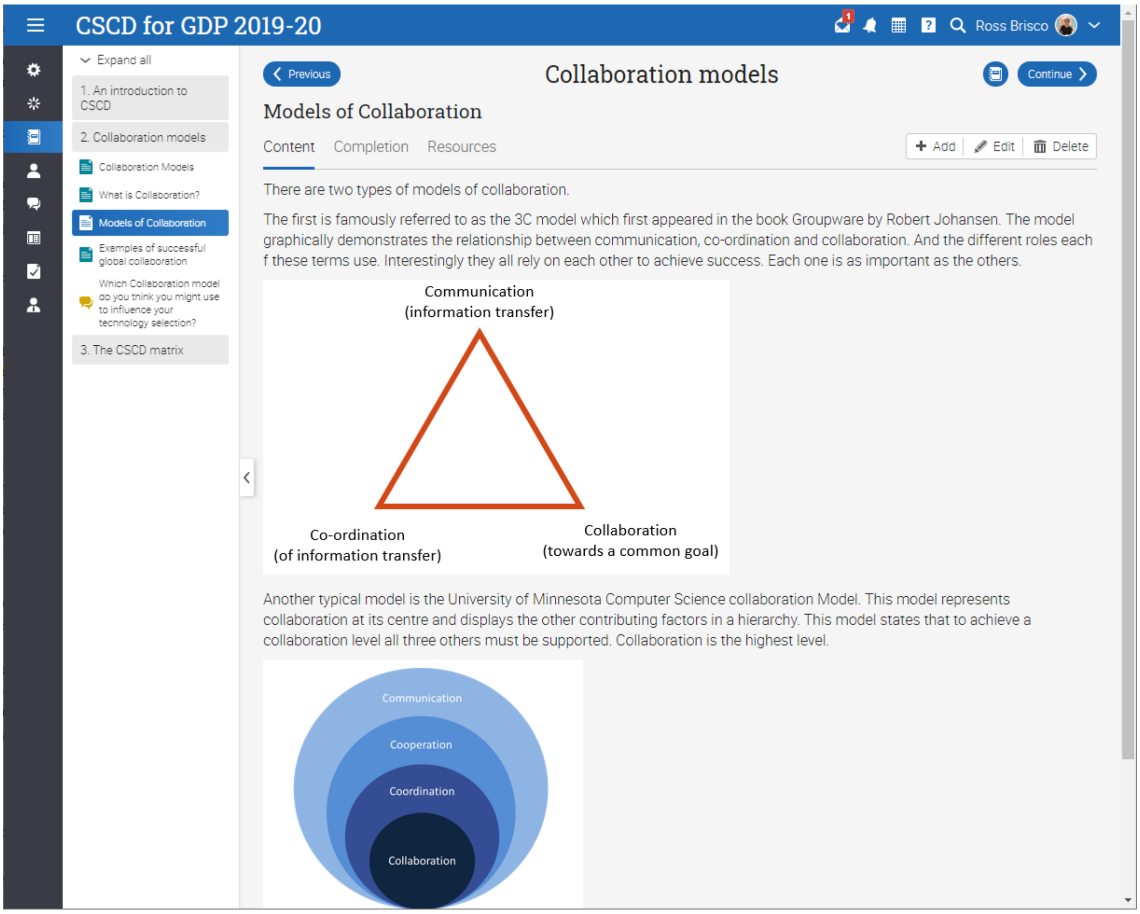


Figure 8-9: The class on Collaboration models

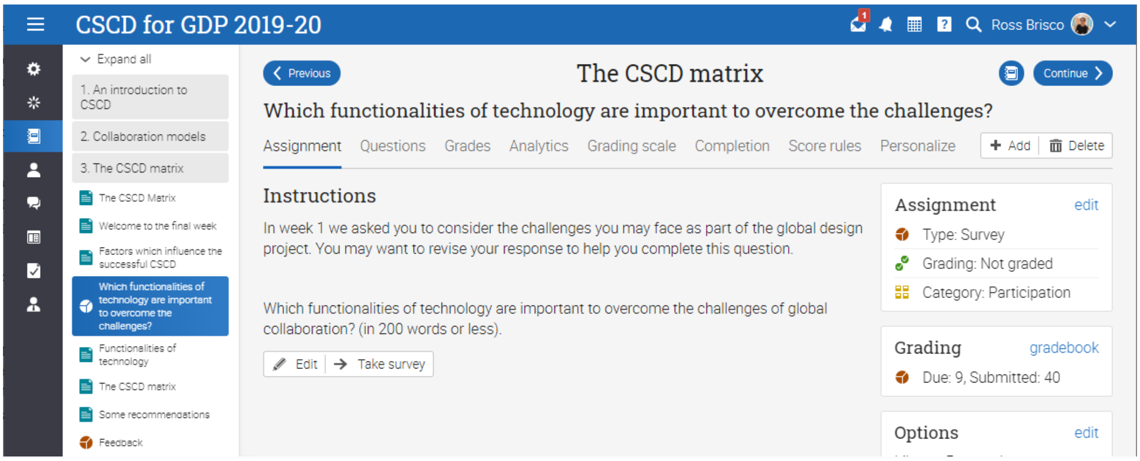


Figure 8-10: An example of a discussion forum to support reflection

Concerning the CSCD matrix, the matrix was introduced and then displayed throughout the lessons. The outcomes of the first lesson were to introduce the technologies that might be used, the second lesson was about the functionalities that might support CSCD, and the third lesson introduces the CSCD matrix itself and how to use it. Feedback from the workshop in 2018 on difficulties understanding how to use the CSCD matrix was addressed by simplifying the activity. Rather than displaying the matrix with the 19 requirements to begin. Students were first given a CSCD matrix example with one requirement, one technology and five functionalities. Once they felt confident, students could move onto the next level Figure 8-11, which continued with four technologies, five functionalities and the six high-level requirements. The rationale for this was to link with Mamo et al. (2015), who recommends the use of four technologies and to simplify the requirements. The work of Mamo was influential in this research and future studies might combine both research outcomes to build an understanding of how technologies can be selected and evaluated for different times in the design process. The toolkit produced by the CSCD matrix is designed to apply to a full design process, however knowing which requirements or which functionality is required at which stage in the design process will enable more productive teams through timely implementation of technologies.

Students had to use the knowledge from the first and second lessons to add in functionality they think is important and to describe the requirements recalling information and building reflection. If students were stuck, connections would allow them to revisit this information. Once comfortable with this simpler matrix, the students would move onto the full matrix, which could be used to complete their technology investigations towards technology selection.

Feedback from the class was used to evaluate how successful the CSCD matrix education was in this format. 38 students responded to the feedback request. Students were asked if they felt the knowledge learned using the CSCD matrix would influence their teamwork. 19 said definitely yes, and 16 said probably yes. Only three students or 8% of respondents, answered probably not. When asked how they might use the CSCD matrix the majority of students answered that the CSCD matrix would support discussion in technology selection at the start of the project or that they would use the CSCD matrix when problems arose. Three students did not respond in this way, and two said they were not sure how they might use it, alluding that they did not understand how to use it and one answered that the knowledge was useful, but they could not understand how to implement the CSCD matrix into the project specifically. Following the specific answers on the CSCD matrix, there were some general comments asking for more examples of projects in future versions of the course and to simplify the content further. The majority of students, 90% stated that the class, as a whole, has prepared them fully for the GDP.

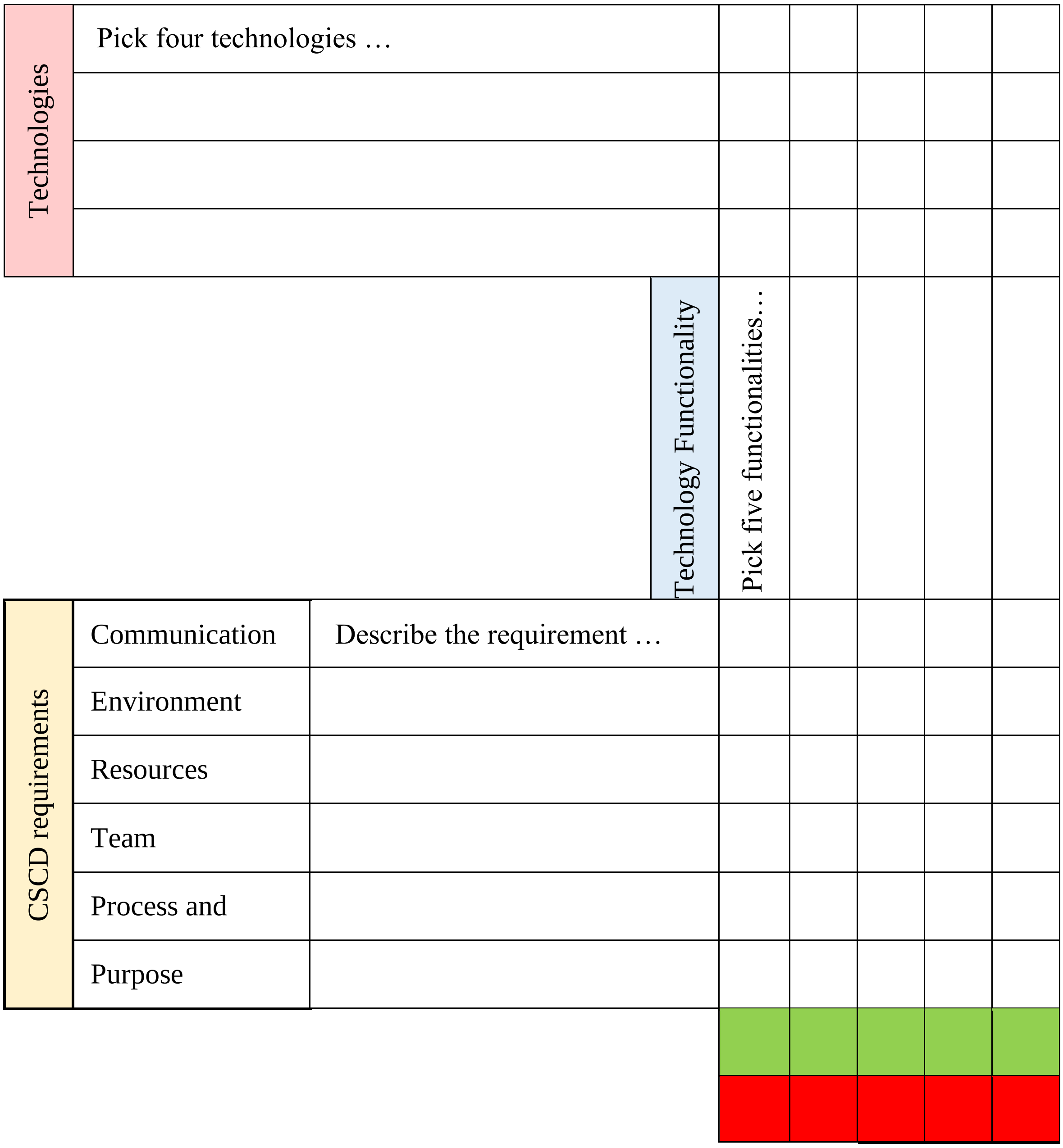


Figure 8-11: The simplified CSCD matrix to introduce concepts to students.

8.1.4 Evaluation of the CSCD matrix for education

As there was still some negative feedback from the online short course in CSCD, experts were identified to evaluate the implementation of the CSCD matrix within an educational environment and make suggestions for further development. Experts were sought within the University of Strathclyde for practical purposes but outside the Department of DMEM so reduce bias towards the success of the project. Materials were prepared to explain the use of the CSCD matrix by students to the experts and to stimulate conversation around its success and development. Fixed questions were not defined to ensure a fully open discussion.

Discussion with Dr Sean Morrissey

Academic Developer within the Organisational and Staff Development Unit

Learning Technologist with experience in VLE's

Dr Morrissey sat for twenty minutes and we discussed how the CSCD matrix supported the selection of technologies. Sean agreed that the matrix was a successful way to profile technologies to support students understanding of the barriers and benefits of each technology, but also the project as a whole.

The matrix

Dr Morrissey began by commending the development of the CSCD matrix in a systematic and recognisable way. He remarked, "Certainly the development of the (CSCD) matrix in a recognisable way supports your aim that it can be a transferable tool into other environments supporting humanities, business studies or another set of students". He added, "The (CSCD) matrix supports a building of students understanding on a problem, first technology, an easy to understand topic for most students, then functionality, recognisable but more abstract, building towards the requirements, very abstract but required for a depth of understanding of the problems. This is very important for students knowledge building". This acted as a confirmation that the structure of the CSCD matrix supports education. Dr Morrissey Did have one suggestion to advances the CSCD matrix for students, "Perhaps, it could be the case that learners could use your method, could successfully identify the best software (technologies) to use but wouldn't know how undertake personal development". By this Dr Morrissey was making a statement on the building of skills in students' education. The workshops and the short course go some way to supporting skills building; however it is not explicit.

Students understanding

One issue that came from the workshop and online course was a lack of understanding of how to use the CSCD matrix after it has been explained. The development from the workshop to the short course was to simplify the CSCD matrix further whist the student is learning it. Dr Morrissey agreed that this was a sensible step towards a better understanding of the CSCD matrix whilst it is still new to students. He added, “Can the (CSCD) matrix be simplified further? Could the functionalities be split into smaller categories like the requirements have been”. On discussion, this suggestion was to abstract the functionalities further rather than having eleven functions that are well defined. This would be possible because of the three higher level categorisation within Mittleman et al. (2015) being jointly authored pages, streaming media and information access tools. This suggestion is worthy of investigation in future studies and workshops. However, these broad definitions of technology functionality may be too intangible for teams to discuss.

A digital tool

Dr Morrissey suggested that the paper-based CSCD matrix may not be the best way to interact with the knowledge. “To support comprehension, a Google sheets tools could be created. And when you hover over the different boxes (spreadsheet cells) It tells you what you need to know to answer fill in the box.” This was a good suggestion and should be included in future classes. It would be very simple to build and test. It might also support outreach and engagement for the tool if it were available to the public.

An introduction

The tool is described currently within the contexts of the GDP and there have been many descriptions of the tool over time in conference and journal papers, and in lectures. However, when the tool is described to students, there are no description of its importance, its development, and its possible use cases. Sean suggested that by conveying these requirements of CSCD to students, they would have a deeper understanding of the tool and a greater appreciation of its usefulness.

Examples

This is a very new tool, and there are a limited number of examples available. Dr Morrissey commented that “The more examples you can show the students the better. Our students grasp the usefulness of a new tool when they see an example which is like their problem. This doesn't mean they copy it, but it clicks in their head how the tool works." Sean went onto discuss how a best-case scenario could be developed. This could be a starting point with the GDP 2018 data, and the CSCD matrixes developed from this. He also suggested that there needed to be a clarifier within the online course. When a student learns about a new tool, they should "see the tool, understand its use, sure, but give them an example. Then test that they understand the example given. Using a forum or a quiz to clarify that they have understood in the correct way." This might support the learners who said they needed a little help to understand how to use the CSCD matrix as it would build confidence that they do know the correct way to undertake the task.

Mapping the student experience

Dr Morrissey suggested the use of a spider diagram to support any further development of the course. There could be five criteria that represent the learning outcomes of the class for example, one could be successful use of the CSCD matrix. After each class, students could rank their understanding, and over time with further workshops, an ideal could be worked towards to build a comprehensive education model for using the tool.

Awareness of the tool

Dr Morrissey had some parting words in terms of the visibility of the tool. If the desire is that more people should use the tool, then there needs to be a plan on how best to market it to them. "A teacher might ask 'how can I teach technology selection to my students'. However, they will also be looking for an exciting and entertaining way to do so." Sean added that "A teacher would never say 'I need a VR headset for my class', but if they were given the opportunity to try a task, they would see the benefit." These comments remind me that many academics are stuck in their ways of teaching from a textbook or an established set of methods. The reasons are quite just as accreditors require some predictability and stability in teaching practices. This does not mean that there cannot be innovation, but it is challenging to sell a new, unproven method. Not only does there need to be a building of examples of the tool working to feedback into education, but also an outreach of the benefits of the tool

Discussion with Dr Doug Bertram

Senior Knowledge Exchange Fellow Civil and Environmental Engineering

Associate Director of the Strathclyde Engineering Online Centre

The CSCD matrix was explained to Dr Bertram over the course of half an hour with questions and discussion. Doug agreed that the CSCD matrix is a systematic and automated tool that supports the selection of suitable technologies.

Focus on visual

Dr Bertram's first impression of the tool was how visual it is. He suggested "The understanding of the tool and the simplicity of the interface are contradictory. When you say 'it is a simple tool' you refer to the process of filling in the (CSCD) matrix. However you do not consider the logical process of understanding all the components and all the parts." This related to Dr Morrissey comment on explaining the creation of the CSCD matrix to users. Dr Bertram continued "Although it is a good effort to get the Requirements down to 19, and I doubt you will be able to condense them further, this might simply be too much for students to comprehend and might explain why some students suggest they would require further help to use the tool." Although we could not discuss a solution, the online tool suggested by Dr Morrissey might be a solution.

Introducing the tool to fast

The entire education experience was explained, and Dr Bertram reacted that although good practice had been put in place to spread out the learning, there could be enough to build an entire 11-week module exploring one or two of the requirements per week. This is a sensible suggestion to break up the work. Although comprehension would be increased, perhaps retention of knowledge and, importantly recall might not. This relates to problem/project-based learning (PBL) as an experience to ensure students are able to build their own knowledge and experiences over time with greater recall. The GDP is a good example of this, and perhaps the CSCD requirements could be integrated within the class better over the course of the semester.

Building slowly

Dr Bertram and Dr Morrissey both agreed that building familiarity with the CSCD matrix was the key to supporting understanding. Dr Bertram suggested a further breakdown of the CSCD matrix components starting with a 4X4X4 matrix. However, he identified that the most significant problem was giving students the time to reflect on the learning. He added, “The requirements seem to be the abstract unknown for the students at this time. Could it be that you build familiarity with the students ahead of the matrix with a different activity? For example, could the students rank the CSCD requirements in order of importance?” This suggestion resonated with other workshops and CPD courses and is a very sensible solution. There appears to be a missing step between hearing about the CSCD requirements and using them in the CSCD matrix. This is a suggestion for future workshops and online courses.

Reframing the matrix

During the discussion, Dr Bertram suggested that the tool and associated learning with the workshops and online course could be beneficial for Continuing Professional Development (CPD) for enterprise customers. He shared how the tool might be framed as a management decision tool, “You have this setup for teams of students to use. It would be easy to reframe this for managers and senior engineers within companies to evaluate technologies, perhaps with input from their teams, to come out with the best answer. I think the first time you run this, it might be difficult to come out with a sensible result, but over time and in building familiarity, it could be very useful within industry.” This was very encouraging for the next steps in developing the CSCD matrix for a wider audience; however, their needs to be a consideration for the level at which the tool is aimed.

An unsuccessful CSCD project

In concluding our discussion, Dr Bertram suggested that understanding success is difficult to define and suggested, “Unsuccessful projects are easier to define. Perhaps you set a challenge of identifying why the project was unsuccessful. Then you use the requirements to change the unsuccessful project into a successful one.” This was very good feedback as in the experience of the workshops, students find it easier to justify a negative result than a positive one. Where a student might easily identify a problem, it is more difficult for them to identify a success other than ‘it met our aim’ or ‘it was easy/simple/fast’. Identification of problems seems to result in more nuanced answers such as ‘it failed for x reason’.

8.2 Future development of educational modules for industry

The success of the CSCD matrix within an education's environment indicates its usefulness as a technology evaluation and selection tool and as a support tool in developing knowledge of CSCD. This is not limited to education but could be employed in a range of sectors to support technology selection. The CSCD matrix is built upon the principles of the E2 Design Activity Model adapted for Collaboration. The model demonstrates how requirements of CSCD can affect the efficiency and effectiveness of design activities by ensuring resources and knowledge are sufficient. Improving efficiency is desired in the industry as identified in the fields of BIM (Shen et al. 2015), PLM (Doumit et al. 2015), PDM (Chu & Chan 2013), and CSCD (Li et al. 2011). The CSCD matrix can support this desire through the identification of solutions to industry problems.

Improving efficiency becomes possible through a greater understanding and analysis of problems using tools. By observing gaps in requirements, a negative challenge can be changed into a positive advantage. Furthermore, an efficiency measurement can support the actions taken based on measurement. If an efficiency measure is not going to be met by a team conducting design activities, then the managers can decide whether to conduct the design activity. The CSCD matrix presents a base for the development of managerial tools and software to understand the strengths and weaknesses of technologies that support CSCD.

Evaluation of the CSCD matrix in the context of industry comes in the form of its value. The value of the CSCD matrix over other methods is agility. A PLM system may require vast investment in new technology and software limited, and this may be limited to a specific vendor. It may or may not adequately meet the needs of the team and the project. The agility of the CSCD matrix enables any potential technology to be profiled and assessed. Toolkits can be created where the individual profile of each technology and the profile of the toolkit as a whole can be displayed. This can take place at the start of a project or whenever required throughout.

It is difficult to launch new technologies within an enterprise setting as in many instances. Companies are 'stuck in their ways'. There are many reasons for this, but prominently a lack of training and a lack of interest by workers are to blame (Garcia-Perez & Ayres 2010). As with student projects. The CSCD matrix and its outputs create a justification for the trial and use of new technologies.

8.2.1 Development of a strategic technology selection method for industry

Following the successful development of the CSCD online course, the same method was envisioned for a CPD course aimed at an enterprise audience. To make the course relevant to todays industries, it was defined by the requirements of Scottish engineering companies. One of the most significant challenges the industry is currently facing is making sense of Industry 4.0 and gaining access to support and expertise. The course was designed to support transformation in digital manufacturing related to industry 4.0.

A one-day CPD workshop was developed for the National Manufacturing Institute Scotland (NMIS) Manufacturing Skills Academy. The workshop is planned to be delivered throughout Scotland and into other select areas of the UK.

The format of the workshop's mimics some of the first CSCD workshops with a focus on Industry 4.0. Technologies are introduced, then drivers for change are explained (analogous with technology functionality) and finally, the requirements of digital transformation within an industry 4.0 context. Following the building of this knowledge, two versions of the matrix tool were introduced, first with the CSCD requirements and then with the Deloitte Digital Maturity Model (Anderson & Ellerby 2018). The Deloitte list of requirements was added to this workshop as they are relevant to digital transformation considerations, and the CSCD requirements were included to demonstrate the use cases of the matrix but also to demonstrate the tool with its collaboration foundations. The five dimensions of the Deloitte Digital Maturity Model are customer, strategy, technology, operations and organisation & culture. These each has sub-dimensions (analogous with the sub-categories), 28 in total, and 179 individual criteria total (analogous with the 220 requirements of CSCD from the literature).

Feedback from the first CPD workshop was highly positive. Although a few tools were taught, the attendees commented in particular on the CSCD matrix as a novel tool that solves the problem of the first steps towards digital transformation. Although road mapping had been attempted before by some attendees within their large companies, the struggle they were having is the first steps to take and identifying the technologies which would support these first steps. The CSCD matrix supports this action. A further comment was the same feedback received during workshops in education. The jump between technology, functionality and requirements was too fast and should be built up over time. An activity could be put in place to support the identification of suitable technologies, functionalities and then focus on requirements. This CDP will be developed as future work based on promising results from an educational context and the pilot workshop.

8.3 Summary

In this chapter, the contribution to knowledge of the research project has been discussed. There are many overlaps in the outcomes of the use of the CSCD matrix and its future development.

Beyond the CSCD matrix as a tool for evaluation and selection, there have been many additional contributions to knowledge. To support the development and evaluation of the CSCD matrix, such as, an in situ workshops and online short course. Feedback from both has been highly positive within an educational environment. Consistent feedback was to simplify the CSCD matrix from students and to introduce the CSCD matrix in a more managed and slower way from experts who were consulted. Initial results of this are positive, and the development of an online short course in CSCD also goes some way to engaging a more extensive range of students in the research.

As students move into careers, it is hoped that they will carry the knowledge of the CSCD matrix as an enterprise strategic technology selection tool with them. Some considerations are discussed and the development of a CPD course as future work.

9 CONCLUSION

The primary research question asked, '*RQ1. Can a systematic automated method be established to support the selection of appropriate technologies that for CSCD in engineering design team projects?*' The CSCD matrix was created to support the evaluation and selection of technology to support CSCD for engineering design team projects. To best understand the relationship between the technologies that support CSCD and the requirements of CSCD, a theory of design activity is detailed. To ensure the identification of the best technologies to support CSCD a systematic identification methodology was established, which included identifying requirements through peer-reviewed literature to support CSCD, the verification of requirements through observation and expert opinions, and the establishment of a list of CSCD requirements. To ensure that the established method was unique and fulfils a gap in the knowledge lessons were learnt from the literature review to establish an automatic population method of the CSCD matrix and an education programme to introduce the basic knowledge required to understand the CSCD matrix and how to use it practically. To understand if the developed method succeeded towards the aim, an evaluation of the research success is discussed using real-world project data, the opinions of experts, and comparison towards the objectives of the research project.

The research began with an investigation into the research area, preliminary literature, and observations of the phenomenon of students using technology to facilitate CSCD. The term CSCD and context were defined built upon academic definitions and CSCD practice. CSCD is influenced by its environment and there are many practices with support CSCD. Supporting CSCD is determined as the motivation of the research with the context of student engineering design projects such as the GDP and others which engage in distributed design. The problem is established that students do not have a systematic method to evaluate technologies that may support their CSCD work, and do not use a systematic decision-making process to select technologies. As a greater number of novel technologies are made available to students as the years progress, there is a design to investigate if a method of technology evaluation and selection can be created.

Preliminary investigations on the motivation for the research took place. A survey was conducted to better understand the change in student behaviour observed in the GDP towards novel technologies such as social network sites, and another survey was conducted to determine the technologies commonly used by students. This revealed how technologies have changed over time. Towards the motivation of the research, the methods of supporting students in technology evaluation and selection were explored in the published literature. An appropriate method for the students of the GDP was not found, however, lessons were learned about successful methods by other researchers and the factors which influenced their success. The motivation for this research details the research contribution to knowledge and the educational contribution. It was determined that there was a need to develop a systematic automated method to allow engineering design teams to evaluate and select suitable technologies to support CSCD.

Upon an understanding of the phenomenon, a research approach was investigated and adopted by the author based upon their understanding of research philosophy and the defining concepts of paradigm, ontology, epistemology and methodology. The world view was discussed and the assumptions made are rationalised towards this view to determine how the outcomes of this research are understood. A research approach map was created detailing all sources of information, all knowledge-building activities and all contributions to knowledge of this research.

A literature search and review was conducted with the purpose of identifying the gap in knowledge and building upon accepted peer-reviewed and published literature. The literature search protocol is detailed for robustness and repeatability. The literature search was split into three investigations aligning with the logic of the CSCD matrix and the investigation. The three areas revealed the requirements of CSCD, the technologies that can be used to support CSCD and the technology functionalities to meet the requirements of CSCD. To fill the gap in knowledge, there is a need to build upon the existing research utilising the existing literature and establish the requirements of CSCD.

Due to the nature of the requirements of CSCD, as identified in several pieces of literature, research activities were conducted to identifying the requirements of CSCD first extracted from literature, and then verified and validated using the knowledge of experts and a categorisation activity. Workshops took place to develop the list of challenges for CSCD which established a categorisation list as appropriate for use. Requirements of CSCD were aligned with the categories to support understanding and enabled the creation of 19 CSCD requirements statements. These statements were confirmed through the use of a survey of experts who provided feedback on each statement and changes required.

The CSCD matrix was developed justified by logic in its creation as the vehicle for the knowledge which addresses the research question. The completed CSCD matrix is presented with the requirements of CSCD and the technology functionalities populated. The CSCD matrix is presented with the technology-functionality matrix detailing which technologies have which functionalities, and the functionality-requirements matrix revealing which functionalities are capable of satisfying which CSCD requirements.

An automated method of populating the matrix was envisioned to reduce the time and specific CSCD knowledge to populate the matrix, enabling a systematic method to be created. This was achieved using a data coding and creation of a software based automatic population method. Data was collected from the GDP 2015, 2016, 2017 and 2018 on the use of technologies that support CSCD. Data was collected from informal interviews with students of the class, recorded in a class diary. Data was also collected from students report. This data is used to create a coding schema with three coders experienced in CSCD. The outcomes of the coding are used to create dictionaries using an inter-coder method for robustness.

The automatic population method for the CSCD matrix using GDP data collected in 2018 reveals insights into technology use and how this supports students CSCD teamwork. Software was used to code the dictionaries into filtered folders with confidence scores where a connection was identified. The connections between technologies, technology functionalities and requirements of CSCD are determined in a systematic way that is systematic, repeatable, and robust. Issues with the population can be easily troubleshooted based on the logic of its creation and can be easily updated by adding new synonyms as technologies change over time. Excel is used to populate the CSCD matrix based upon the processed data which enables the creation of the CSCD matrix with multiple levels of confidence.

The outcomes of the method for the GDP 2018 are displayed demonstrating the successful implementation of the method. Multiple confidence levels are produced as produced by a simple excel lookup function from data produced by the text processing software. The data is discussed and differences between the levels reveal the nature of technology support for CSCD to meet the requirements.

To conclude the research, a discussion of the findings of the educational contribution of the method and research contribution. The implications of the contributions to knowledge are discussed, with a focus on an educational setting. The development of the CSCD matrix within an enterprise setting are discussed in the context of future work. Limitations of the work are highlighted including primarily the focus on the GDP. A reflection on the research method chosen is made considering the practical implications of the work, its relation to the theories of education and collaboration, and the unexpected results in developing and conducting workshops and classes with students on CSCD. The initial research is evaluated to determine if the aim '*to develop a systematic automated method to allow engineering design teams to evaluate and select suitable technologies to support CSCD'* was achieved.

The research was built upon a motivation of an observed problem. This both supported the identification of the focus of the research at an early stage, and limited the research journey. The research was reactive to identified problems and had many changes as the project progressed and the phenomenon changed from year to year. An initial focus on social network sites suggested that a solution was difficult to develop for such a niche area. When the scope was widened to technologies for CSCD the significance of the research was realised.

The time scale for this research was also a limiting factor for two primary reasons. Evidently the PhD has a limit in terms of how long the project can continue, and all research work had to be completed within this time frame, but also, the GDP was a semester 1 class at the University of Strathclyde meaning that research could only be conducted within 11 weeks of the year. This influenced the decision to conduct the research over time across multiple years of the GDP. This is a unique insight that research does not often produce. To enable this, considerations for the selected research approach were changed from what may have been a more robust PhD submission overall.

The solution produced to support technology evaluation and selection is a fixed moment in time. To fully realise the potential of the method, more data is required. This is possible as projects such as Gopsill (2014) are based upon multiple years of research originating from work in a research group starting in the mid 1990's. This research was able to collaborate with the Global Studio on workshops, however, due to individual university regulations, further collaboration was not possible to acquire data. This research be a first step which has the potential to influence other projects and foster relationships to support future technology evaluation and selection for a wider range of CSCD projects.

The 19 CSCD requirements are a contribution to the knowledge from this research. Such a list of requirements has never been created for engineering design teams. To ensure a robust list, several actions were taken to verify and validate the data. Although robust, a complete list cannot be claimed as there is no way to validate the completeness. The 19 CSCD requirements act as CSCD dogma for engineering design teams created for the CSCD matrix, but may be valuable for other CSCD research in the context of engineering design.

Using a better understanding of the CSCD requirements, technologies that support CSCD and the technology functionalities, the influences on design activities towards design tasks can lead to more appropriate design activities, tools, and methods. The model gives a framework to define future research work; however, this is as yet undefined and requires collaboration across institutions, global classes and a coordinated, collaborative effort.

An automated population method was created to analyse text in a familiar format to engineering design teams. Building upon the work to create QFD inspired matrixes in the past, the auto-population method of the CSCD matrix enables a systematic and reliable method for comparison between classes, over the years, or towards more generalisable results with future research. An evaluation of the auto-population method was discussed with consideration of the success with the GDP 2018 data. The vast majority of connections between criteria were expected, and evidence was found to confirm genuine connections. However, further investigation is required to understand why a minority of results were perhaps unreliable due to a lack of data or inaccurate or incomplete coding.

Whilst a focus on CSCD and distributed design has limited the generalisability of the outcomes of this research project, the developed method with a focus provides deeper insights into the issues that affect CSCD projects within an understandable and comparable context. While more generalisable results would potentially support more interests, there are many papers discussing collaboration issues within the literature that offer their own opinions based upon previous studies. The CSCD focus has enabled a new dimension for this research field with less holistic and opinionated analysis and more systematised and confident analysis. The CSCD focus is not a common feature of research within the field and promotes research integrity in a common context.

In conducting this research, new questions have emerged, excluding the investigation into an enterprise context or beyond the distributed design context. Many questions have been raised towards blended environments. Where technology is essential for distributed design, it is prevalent within collocated environments or where a mix of collocated and distributed is required. These blended environments more closely represent CSCD within an enterprise environment and blended environments. Unfortunately, there is limited pursuit of reporting of these blended environments on how collaboration supports design activities. This would require new models and a new understanding of interactions between team members. The method taken to develop the CSCD matrix would likely not be appropriate entirely to this problem due to the lack of existing reporting. However, this could be a start with further development and several observational studies.

Throughout this research project, there have been many outcomes that contributed towards best practices or lessons learned for academics and practitioners of engineering design in distributed situations. The outcomes of the CSCD matrix apply to the GDP of which future years can benefit from the analysis of this data. One of the primary motivations for this research project was students use of newer technologies within design education and education in general. Social network sites offer a way for students to be connected and to communicate. Additional functionalities support tagging and syndication. However, these were not well used or reported within the GDP project in 2018. These functionalities support many problems students face, including awareness, and students should use these functionalities more to satisfy CSCD requirements.

The CSCD matrix has merit in supporting the selection and justification of technologies for use in globally distributed design projects. Distributed design teams should be encouraged to use the CSCD matrix in the future within the given context and should be encouraged to take the methodology detailed and amend the knowledge to fit other scenarios. These new matrixes should be traceable and usable for others. To support traceability and usability, an approach should be identified connected to a repository supporting the collection and distribution of this knowledge. The first steps towards this are being developed with consideration for the implementation of Industry 4.0 technologies within an enterprise setting.

As an educational tool, the CSCD matrix enables students to evaluate and select suitable technology, but also to explore the issues they might face during distributed projects. Awareness of CSCD problems supports their education of the projects in general and prompts reflection. The online short course in CSCD developed transfers knowledge to the students through examples of CSCD projects, how they have been successful in different contexts, and how they might learn from what has come before.

Future study is required to understand better the impact that polling tools functionality, audio conferencing functionality social tagging system functionality, search engine functionality and syndication tool functionality can have on the design project. In addition, the requirement of motivation was underpopulated and required further study.

The research enabled an investigation into assumptions made about CSCD work. The rise of social network sites observed in student projects enabled students to conduct CSCD projects, however, it was unknown how successful these technologies are in supporting education aspects. From the GDP2018 data in the CSCD matrix, it is now known which requirements that social network sites support, and this can be compared to other technologies. Certainly, the combination of tools as a tool kit enabled the identification that video conference is a tool that could be used more prominently in projects. But as discussed above, the change in how we think about technology due to COVID19 and working from home has increased the use of video conference for all. This new phenomenon may change how CSCD is conducted and the acceptance of technology, and the technology evaluation and selection method enable a way for this to be measured, tracked, and compared over time. This enables future research into the use of existing and novel technologies in a systematic and justifiable way.

Towards the aim, this research has contributed in multiple ways. The CSCD matrix developed is a tool that supports the evaluation and selection of suitable technologies. This is achieved based on existing knowledge from the literature collected during a systematic literature search. The process is automated to support the population and is robust documentation of the process. The outcomes of this study focus on the field of CSCD for engineering design teams, particularly those in an educational environment and working distributed.

The aim was established to ensure that all aspects required of a CSCD matrix were included, such as systematic and automated population, based on existing literature and expert opinions from multiple sources, towards a particular problem being CSCD for distributed engineering design teams and enabling evaluation of multiple technologies as a tool kit, one technology on its own, or from the perspective of the requirements.

The CSCD matrix is a tool that will be used in future GDP to support the evaluation and selection of technologies towards the aim. This tool and its method of creation can be used to create augmented tools for other contexts or to update the CSCD matrix over time as technologies change. This thesis is successful in documenting its creation and discussing its usefulness as a substantial original contribution to knowledge.

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APPENDICES

Appendix 1: Permission to include publications within this thesis

rossbrisco@hotmail.co.uk

From:	DS PRESIDENT <president@designsociety.org>
Sent:	16 October 2019 20:20
To:	'Ross Brisco'
Subject:	RE: Permission to reprint articles

Dear Ross

On behalf of the Design Society I am pleased to hereby grant you approval to reprint the articles detailed in your mail, below, as part of your PhD thesis.

I wish you all the best of luck in completing the thesis and in the following examination.

Kind regards

Tim McAloone

____
Tim C. McAloone
Professor, PhD

President of The Design Society
www.designsociety.org
president@designsociety.org

The Design Society is a charitable body, registered in Scotland, number SC 031694.

From: Ross Brisco <rossbrisco@hotmail.co.uk>
Sent: 16. oktober 2019 21:10
To: president@designsociety.org
Subject: Permission to reprint articles

Dear Prof. Tim McAloone,

I am writing to ask for your permission in your role as president, to reprint the following articles published by *The Design Society* as part of my PhD Thesis.

E&PDE 2019
Overcoming the challenges of global collaboration through design education
Ross Brisco, Robert Ian Whitfield, Hilary Grierson, Erik Bohemia
Paper presented at the 21st International Conference on Engineering and Product Design Education, Glasgow, United Kingdom.

E&PDE 2018
Are social network sites the future of engineering design education?
Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.
Paper presented at the 20th International Conference on Engineering and Product Design Education, London, United Kingdom.

Design 2018
Modelling the relationship between design activity and computer-supported collaborative design factors.
Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.
Paper presented at the 15th International Design Conference, Dubrovnik, Croatia.

ICED 2017

1

The use of social network sites in a global engineering design project.
Brisco, Ross; Whitfield, Robert Ian; Grierson, Hilary.
Paper presented at the 21st International Conference on Engineering Design, Vancouver, Canada.

E&PDE 2016
Recommendations for the use of social network sites and mobile devices in a collaborative engineering design project.
Brisco, Ross; Whitfield, Robert; Grierson, Hilary.
Paper presented at the 18th International Conference on Engineering & Product Design Education, Aalborg, Denmark.

Thank you for your response,

Yours sincerely,
Ross Brisco

2

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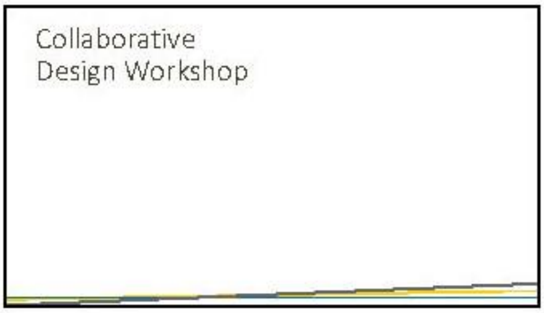
Appendix 2: Slides of the Collaborative Design Workshop



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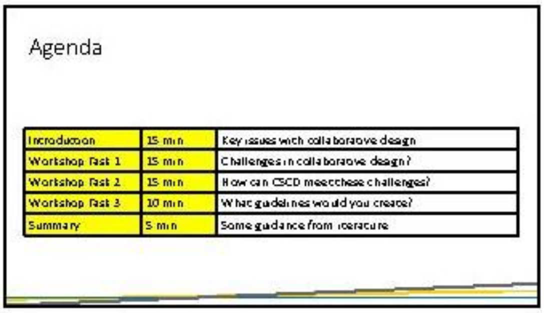

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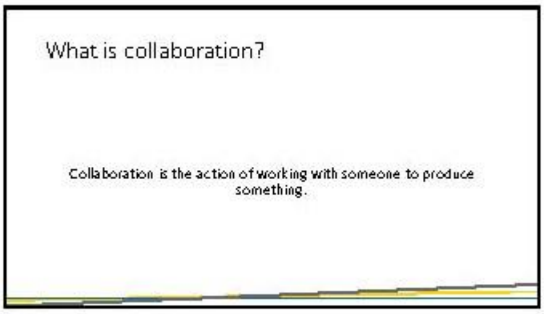

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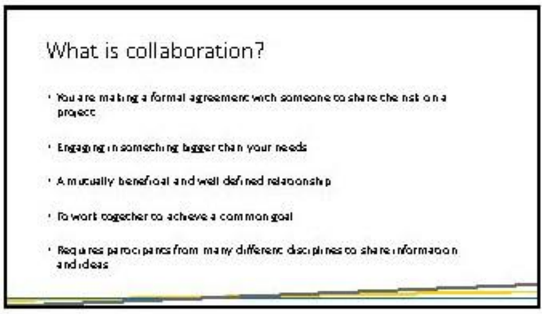

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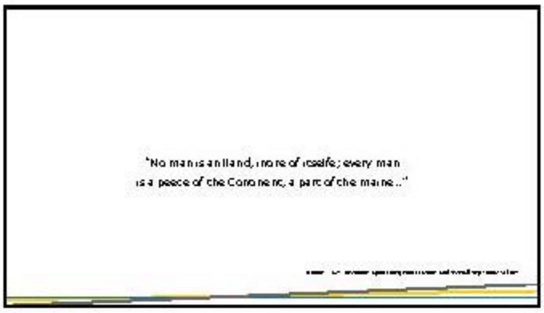

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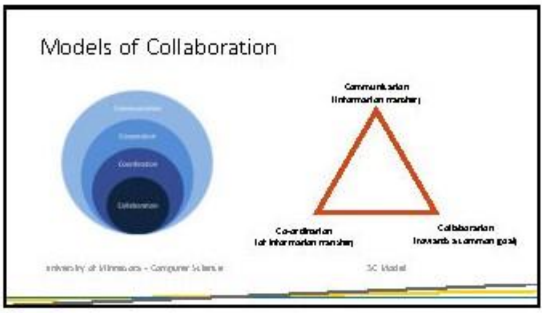

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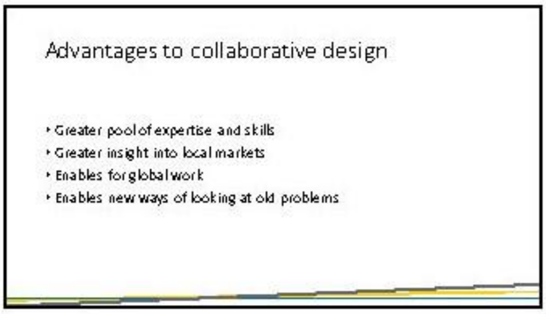
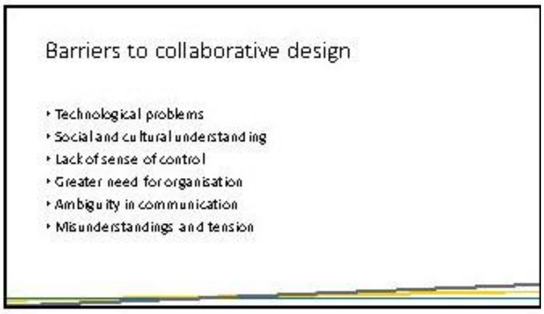
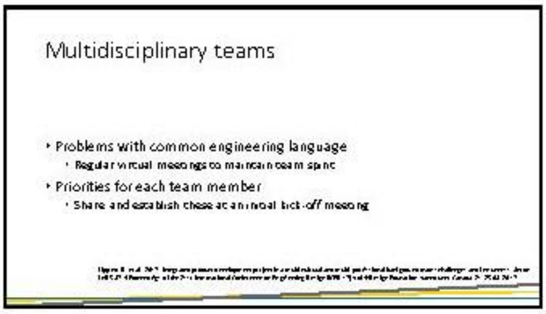

Advantages to collaborative design
Greater pool of expertise and skills
Greater insight into local markets
Enables for global work
Enables new ways of looking at old problems

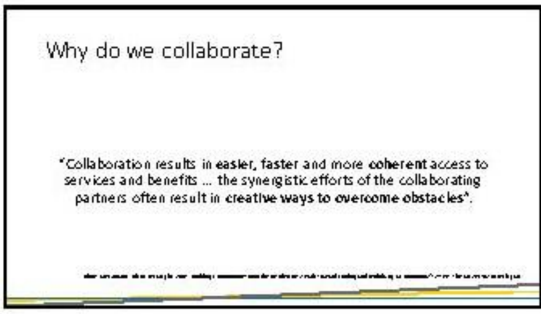
7


Barriers to collaborative design
Technological problems
Social and cultural understanding
Lack of sense of control
Greater need for organisation
Ambiguity in communication
Misunderstandings and tension

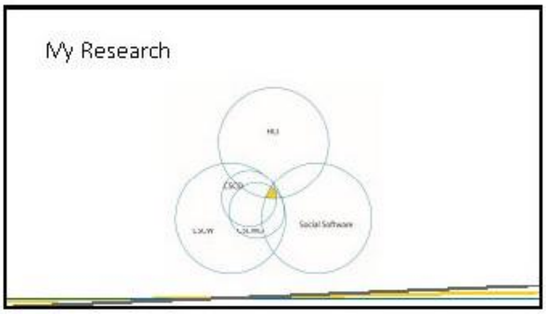
8


Multidisciplinary teams
Problems with common engineering language
Regular virtual meetings to maintain team spirit
Priorities for each team member
Share and establish these at an initial kick-off meeting

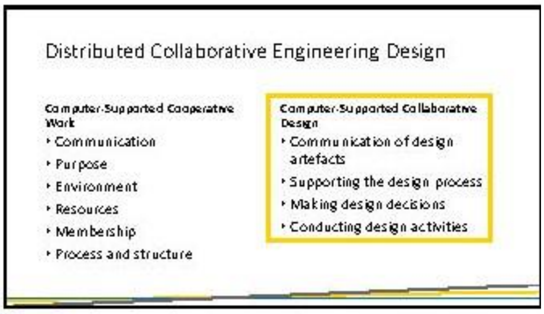
9


Why do we collaborate?
"Collaboration results in easier, faster and more coherent access to services and benefits … the synergistic efforts of the collaborating partners often result in creative ways to overcome obstacles".

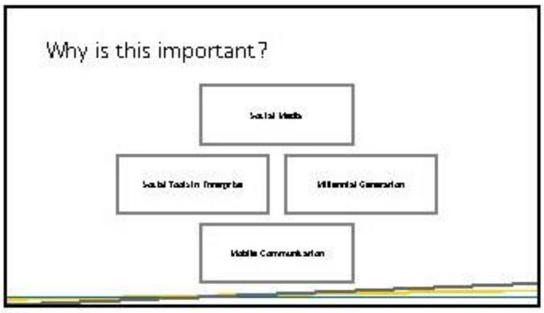
10


My Research
Social Software

11


Distributed Collaborative Engineering Design
Computer-Supported Cooperative Work
Communication
Purpose
Environment
Resources
Membership
Process and structure
Computer-Supported Collaborative Design
Communication of design artefacts
Supporting the design process
Making design decisions
Conducting design activities

12



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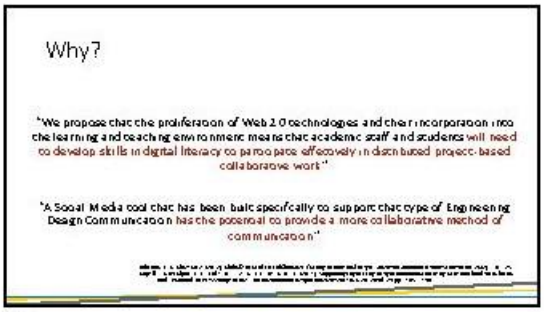

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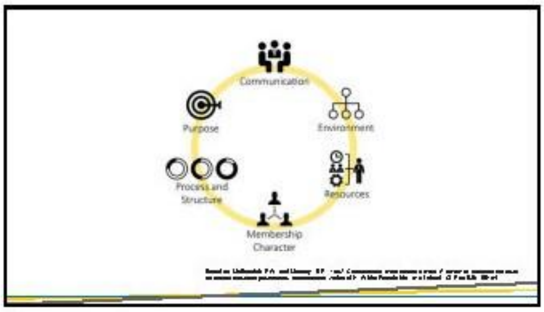

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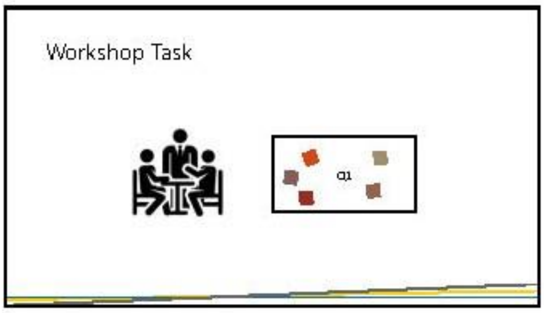

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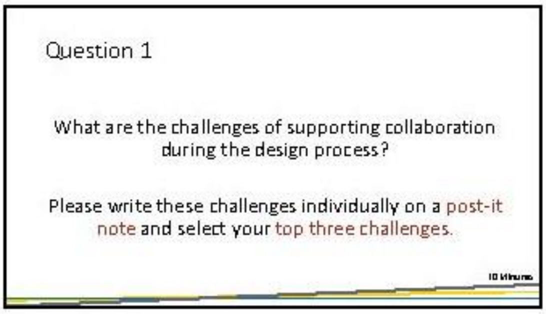

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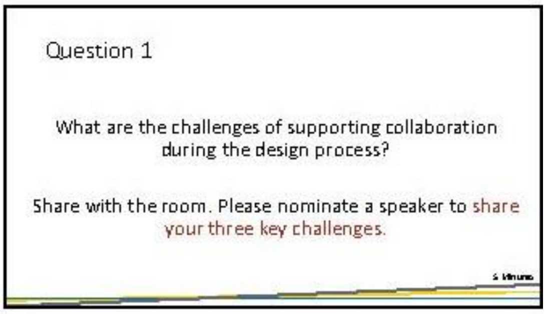

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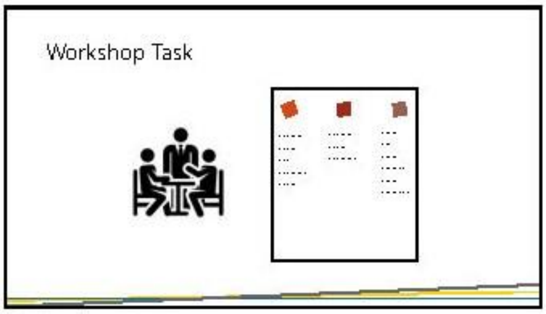

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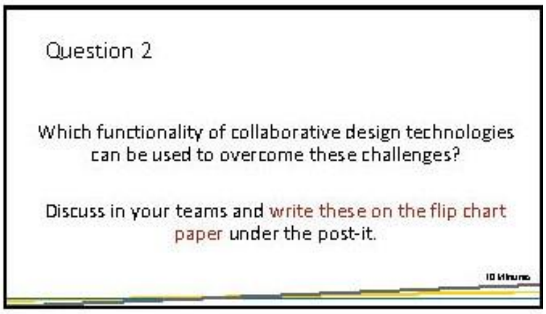

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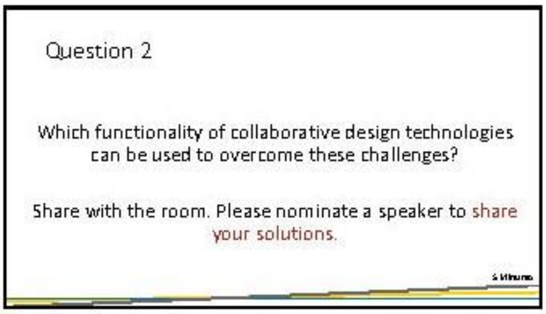

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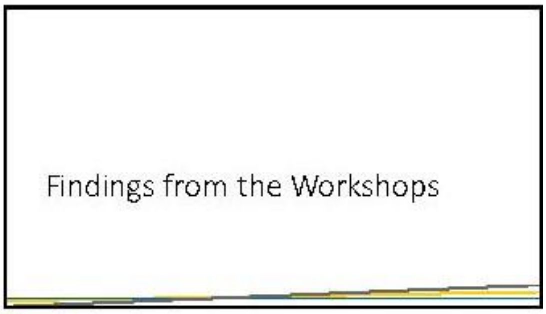

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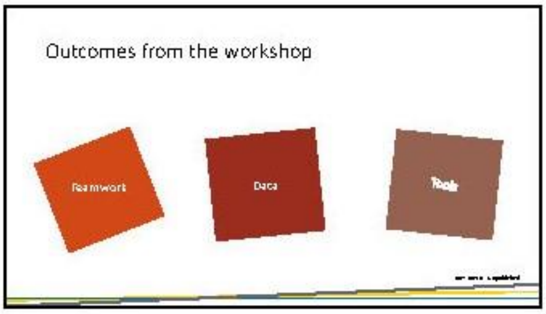

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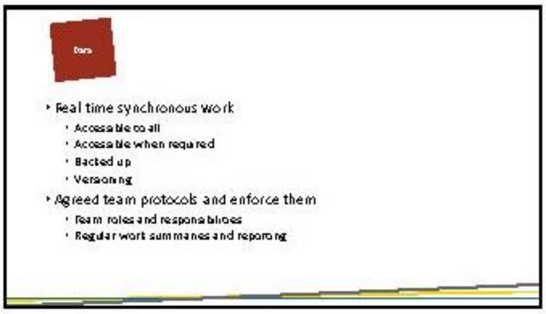

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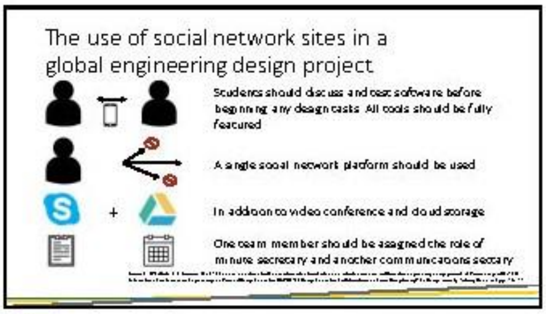

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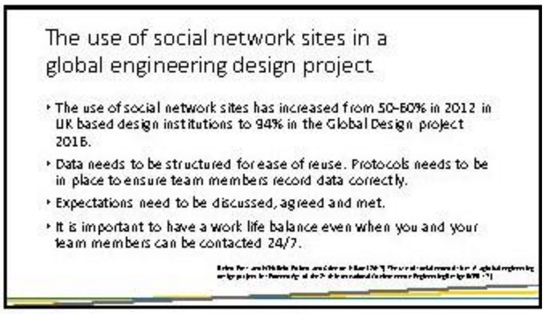


30

Appendix 3: Literature synthesis matrix

Paper	Technology Tools and Methods	Case Studies and Reviews	Knowledge Management	Human Factors	User Participation
Abelein and Paech 2013		X			
Sun and Xu 2012	X				
Ahram, Karwowski and Amaba 2011	X				
Alenquer & Gan 2011	X				
Ane, Roller 2011	X				
Ane, Roller and Abraham 2012	X				
Annett, Grossman, Wigdor and Fitzmaurice 2011	X				
Anticoli and Toppano 2011	X				
Antle, Bevans, Tanenbaum, Seaborn, and Wang 2011		X			
Antunes, Ferreira, Zurita, and Baloian 2011			X		
Baldwin and Von Hippel 2011	X				
Ballejos and Montagna.			X		
Barrett, Goulding and Qualter 2013			X		
Basheri, Burd and Baghaei 2012	X				
Bashouri and Duncan 2014			X		
Bassiti and Ajhoun 2013			X		

Bastos and Dos Santos 2012	X				
Benolken, Wewior and Lang 2010	X				
Bertoni and Ericson 2012			X		
Bittner, and Leimeister 2013				X	
Bjögvinsson, Ehn and Hillgren 2012					X
Boer and Donovan 2012					X
Borsato and Peruzzini 2015		X			
Bortis and Gerald 2010	X				
Bortolaso, Bach and Dubois 2011	X				
Bower 2011	X				
Brown, Recker and West 2011	X				
Brut, Soubie and Sedes 2011	X				
Cai, He, Li and Wu 2015	X				
Camba, Contero and Salvador-Herranz 2014	X				
Carneiro and Li 2011	X				
Carulli, Bordegoni and Cugini 2012	X				
Chen and Guo 2010	X				
Chen Zhao and Cao 2013			X		
Cho and Cho 2014		X			
Chu and Chan 2013	X				
Chu, Li, Liu and Tang 2012	X				
Chung 2012	X				
Chunxiao and Tingyue 2012	X				
Cornelius, Nguyen, Hayes and Makena 2013				X	

Dai, Matta and Ducellier 2014			X		
Dalsgaard, Halskov and Basballe 2014			X		
de Souza, Tacla, Beal, Paraiso, and Gimenez-Lugo 2013			X		
Détienne, Cahour, Legout, Gourvennec, Relieu and Coppin 2012	X				
Dong, Ma, Li, Xue and Jia 2010	X				
Donovan, Heinemann, Matthews and Buur 2011				X	
Dou, Zong and Nan 2016					X
Dove and Jones 2014				X	
Du, Jing and Liu 2010	X				
Du and Liu 2011			X		
Duan and Wang 2012	X				
Esparragoza, Nunez, Lascano, Ocampo, Vigano and Duque 2015		X			
Essén, and Östlund 2011					X
Evans, Gao, Martin and Simmonds 2014	X				
Faste 2012		X			
Faus and Grimaldo 2011	X				
Favi, Germani, Marconi, Mengoni, and Tirabassi 2011	X				
Forsyth and Martin 2012				X	
Franzago, Muccini and Malavolta 2014	X				
French, Stone, Nysetvold, Hepworth and Red 2016	X				
Fruchter and Bosch-Sijtsema 2010	X				

Fruchter and Courtier 2010				X	
Fu, Jiang and Zhu 2012	X				
Fullmer Jr. and Mavris 2010	X				
Gaye and Tanaka 2011				X	
Gericke, Gumienny and Meinel 2010	X				
Gericke, Gumienny and Meinel 2011	X				
Geyer and Reiterer 2010	X				
Goh, Chen, Trinh, Tan and Shou 2014	X				
Goh, Fitriani Goh, Tan, Menon and Cohen 2011	X				
Gopsill, Payne and Hicks 2013			X		
Gopsill, Mcalpine and Hicks 2013	X				
Gumienny, Gericke, Quasthoff, Willems and Meinel 2011	X				
Håkansson and Nergård 2012	X				
Hall, Jones, Bermell-Garcia and Hansen, D David 2015	X				
Hansen and Dalsgaard 2012					X
Hartmann, Morris, Benko and Wilson 2010	X				
Herrick 2011		X			
Herrmann, Nolte and Prilla 2012	X				
Hirlehei and Hunger 2011	X				
Hong, Yu and Chen 2010		X			
Horváth 2012	X				
Hsu 2013		X			
Hussain and de Bruijn 2010				X	

Hussain and de Bruijn 2011	X				
Hyo-Jeong 2010		X			
Iacob 2011	X				
Iacob 2012	X				
Iacob and Damiani 2011	X				
Ibayashi, Sugiura, Sakamoto, Miyata, Tada, Okuma, Kurata, Mochimaru and Igarashi 2015	X				
Imai, Imai and Hattori 2013		X			
Imai, Moritoh and Imai 2012		X			
Inayat, Salim and Kasirun 2012				X	
Jakobi and Stevens 2013					X
Jiang, Liu, Ning and Liu 2012	X				
Jinghua, Liyi and Hongxiang 2014	X				
Johannessen and Ellingsen 2012					X
Jones, Kendira, Lenne, Gidel and Moulin 2011	X				
Jordan and Schallert 2013		X			
Kane, Hurst, Buehler, Carrington and Williams 2014		X			
Kangas, Seitamaa-Hakkarainen and Hakkarainen 2011 (1)		X			
Kangas, Seitamaa-Hakkarainen and Hakkarainen 2011 (2)		X			
Kasprzok and Smith 2014					X
Katjivirue 2014					X
Katz and Te'eni 2014				X	

Kleffmann 2014 (1)	X				
Kleffmann 2014 (2)	X				
Kleffmann, Book, Hebisch and Gruhn 2014	X				
Kleffmann, Hesenius and Gruhn 2015	X				
Kleffmann, Röhl, Gruhn and Book 2015	X				
Koutsabasis, Vosinakis, Malisova, Paparounas 2012	X				
Kumaragurubaran, Viswanathan 2012	X				
La Luz-Houchin, Susana B 2011	X				
Lee, Chan, Ho, Choy and Ip 2015					X
Leon, Doolan, Laing, Malins and Salman 2014	X				
Leon and Laing 2013 (1)	X				
Leon and Laing 2013 (2)	X				
Li, Yang, Li and Li 2011	X				
Li, Yu, Wang and Liu 2010	X				
Li, Xie, Sun, Liu, and Zheng 2010	X				
Li, Dong, Untch, Chasteen and Reale 2011		X			
Li, Tang and Wang 2015	X				
Li, Nahar and Fung 2015			X		
Li, Mou and Yu 2010	X				
Li, Zhang and Zhang 2011	X				
Liapis, Kantorovitch, Malins, Zafeiropoulos, Haesen, Lopez, Funk, Alcantara, Moore and Maciver 2014				X	
Lim and Zakaria 2015	X				

Lin, Tu, Chen and Huang 2013					X
Lin, Chou, Shiau and Chu 2013			X		
Liu, Ramirez-Serrano and Yin 2011					X
Liu, He, Li and Huang 2010	X				
Liu and Jiang 2012	X				
Liu, Hu and Jiang 2012			X		
Liu and Hongfei 2013				X	
Liu and Hu 2013				X	
Liu and Lou 2014	X				
Lloyd 2013		X			
Luck 2013				X	
Lukosch and Kolfschoten 2011	X				
Lund, Prudhomme and Cassier 2013		X			
Magal-Royo, Jorda-Albiñana and Lozano-Suaza 2013					X
Maier and Hess (Not That Maier) 2014	X				
Maier and Schmidt (again not that Maier … a new one) 2015	X				
Mangano, LaToza, Petre and van der Hoek 2014	X				
Marin, Noël and Thi 2014	X				
Matta, Ducellier and Djaiz 2013			X		
Meschtscherjakov Gschwendtner Tscheligi and Sundström 2013					X
Mhouti, Nasseh and Erradi 2014		X			
Mi, Wang, Fu and Zheng 2013	X				

Ming, Jinfei, Qinghua and Yuan 2010	X				
Mohamad, Ibrahim and Mohamed Khaidzir 2015	X				
Morita and Burns 2014				X	
Motti and Raggett 2013	X				
Muller-Tomfelde and Fjeld 2012	X				
Newman, Ferrario, Simm, Forshaw, Friday and Whittle 2015					X
Ni Xiaohong 2012	X				
Nielsen and Bødker 2010					X
Nieters and Bollman 2011					X
Norouzi, Shabak, Embi and Khan 2015	X				
Nováková, Treyer, Schmitt and Achten 2012	X				
Pan, Sun, Peng and Zhao 2012	X				
Pavkovic, Štorga, Bojcetic and Marjanovic 2013			X		
Pedell, Vetere, Howard, Miller and Sterling 2014	X				
Pfister and Eppler 2012			X		
Rahmawati and Utomo 2014			X		
Rahmawati, Utomo, Anwar, Negoro and Nurcahyo 2014			X		
Rapanta, Maina, Lotz and Bacchelli 2013	X				
Ruan and Qin 2011	X				
Ruan and Qin 2011 (2)	X				
Sadeghi, Noel and Hadj-Hamou 2010	X				

Salvador-Herranz, Bano, Contero and Camba 2014	X				
Sandkuhl 2010			X		
Sangiorgi 2012	X				
Sangiorgi and Vanderdonckt 2012	X				
SangSu Choi, HyunJei Jo, Boehm and Sang Do Noh 2010	X				
Sauppé and Mutlu 2014				X	
Schaffer, Chen, Zhu and Oakes 2012		X			
Schneider, Moraes, de Souza and Esteves 2012					X
Shen, Barthès and Luo 2015		X			
Shen, and Lu 2012		X			
Yang, Huang, Hu and Li 2010			X		
Singh, Dong and Gero 2013	X				
Singh, Dong and Gero 2013 (2)	X				
Son, Na, Kim and Lee 2014	X				
Song, Wei, Deng, Du, Zhang and Nie 2015	X				
Steen 2013					X
Stokic, Scholze, Decker and Stobener 2014	X				
Sun, and Xu 2012	X				
Sun, Fan, Shen, Xiao and Chen 2011	X				
Sun and Zhang 2012	X				
Sun, Xiang, Chen and Yang 2015					X
Sutcliffe, Thew and Jarvis 2011	X				
Thornton 2014					X

Van Bouwel, Vande Moere and Boeykens 2012					X
van den Hoven and Mazalek 2011				X	
van Dijk and van der Lugt 2013				X	
Vargas, Zárate, Murillo, Ortega, Reyna and Sierra-Romero 2012	X				
Volpentesta, Ammirato and Sofo 2011		X			
Voogt, Laferrière, Breuleux, Itow, Hickey and McKenney 2015		X			
Vyas, Nijholt, Heylen, Kröner and van der Veer 2010	X				
Vyas, Nijholt and van der Veer 2010	X				
Vyas, Veer and Nijholt 2012		X			
Walsh, Druin, Guha, Bonsignore, Foss, Yip, Golub, Clegg, Brown, Brewer, Joshi and Brown 2012	X				
Wan, Chang and Mo 2012	X				
Wang, Wang, Yang and Lin 2012			X		
Wang and Terano 2015	X				
Wang and Takahashi 2012			X		
Wang, Shih and Chien 2010	X				
Wang and Dunston 2013	X				
Wang, Shi, Wang and Zhang 2010	X				
Wangsa, Uden and Mills 2011			X		
Wang, Hu and Liu 2011	X				
Wodehouse, Grierson, Breslin, Eris, Ion, Leifer and Mabogunje 2010		X			

Wu, Morlock, Pande, Rosen and Schaefer 2013					X
Wu, Rosen, Panchal and Schaefer 2015			X		
Wu, Corney and Grant 2014					X
Wu and Yang 2015		X			
Wubishet, Bygstad and Tsiavos 2013		X			
Xie, Wu, Luo and Hu 2010		X			
Xu, Zheng and Guo 2010	X				
Xu, Ming, Song, He and Li 2014			X		
Shaojin, Jianjun and Jindou 2010	X				
Zheng, Shen and Sun 2010	X				
Yin, Qin and Holland 2011			X		
Yiu 2013		X			
Zhang 2011	X				
Zhang 2010	X				
Zhang, Hu, Zhang and Li 2013	X				
Zhang, Li and Zhang 2015	X				
Zhen, Jiang and Song 2011			X		
Zheng and Feng 2012	X				
Zhu, Mussio, Barricelli and Iacob 2010			X		
Zhu, Mussio and Barricelli 2010			X		
Zhu, Vaghi and Barricelli 2011	X				
	130	31	31	18	24

Appendix 4: 220 requirements of CSCD

Author	**Factors which influence successful CSCD**
Antunes et al. (2011)	Encourage synergy of team; be provided with positive reinforcement to encourage information flow; support contextualisation over distance; support contextualisation with relationships; share a global view in the aid of a shared understanding; share a global view to reduce information overload; reduce difficulties in coordination due to technical difficulties.
Benolken et al. (2010)	Allow for shared visualisation of work; support the organisation of meetings; support audio and video conferencing; allow for messenger style communication.
Bittner and Leimeister (2013)	Convey individual personality; encourage team familiarity; organisational culture; authority; have an understanding for the impact of physical proximity; be incentivised in their work; be in good morale; performance (quantity of output); assist in the reduction of iterative loops; assist in the reduction of rework; support group member satisfaction; have a diverse range of skills; have individual skills; coordination; support innovation; performance (quality of output); support communication.
Borsato et al. (2015)	Allow for serendipitous communication; encourage networking; support a pervasive experience; make team members aware of work; cooperate with each other; coordination; support collaboration.
Cho and Cho (2014)	Enhance interpersonal skills; accept a sense of lack of control; avoid miscommunication; ensure equal participation by all; allow for greater opportunities to express opinions; learning negotiation skills; more thorough outputs; ensure efficiency in communication; productivity; enhance communication skills; ensure more capable employee skills; more creative outputs.

Author	**Factors which influence successful CSCD**
French et al. (2016)	Be encouraged to have a long-sustained interest in the project; be made awareness of other team member's actions; allow for a constant connection; more opportunities for peer learning and training; greater retention of learning; encourage greater team trust when required; allow for improved decision making; greater likelihood of catching mistakes; faster design through collaboration; reduced rework time; reduce complexities whilst sharing data.
Fruchter et al. (2010)	Allow for feedback on ideas; support resolution of discussions; present information in an easy to understand way; allow for clarification of a statement; allow for explanation of a statement; allow for negotiation; allow for the asking of closed questions; assist in negating scheduling problems; support exploration; support problem solving; reduce technical problems.
Gericke et al. (2010)	Allow for the capture of meeting information; support the reuse of data; integrate with data storage systems.
Gopsill et al. (2014)	Allow response with high quality representation examples; provide an electronic or physical reference for communication; allow team members to add comment to past communication; allow team members to define a response to communication; seek input from parties outside the design team; allow the ability to define the purpose of a conversation; allow for the capture of high quality representation of artefacts; allow for the recording of modifications to the artefact; allow for text based description; record and capture the focus of the conversation; limit the size of the response; include the ability to conclude a conversation thread; allow for the organisation of communication by grouping; allow for the response to be coordinated to the correct purpose; allow for the categorisation of communication; allow for referencing previous communication; allow for organisation of communications; allow for easy linking between communications; allow for pushing of information; support the

Author	**Factors which influence successful CSCD**
	answering of multiple threads through a single response; support multi-threading conversations.
Hansen and Dalsgaard (2012)	Allow for the documenting of decisions; allow for the reflection on work and decisions; support an aligning effort of their team members; support the rapid transformation of ideas; support the proposition of design change; support design change.
Herrmann et al. (2013)	Allow for the addition of artefacts to text-based ideation; allow access to edit documents; encourage team members through gamification; be made aware and notified; support rework after the fact; support easy switching between ideation topics; support synchronous working with live documents.
Hirlehei and Hunger (2011)	Difference in time zone; have a cultural awareness for distributed team members; discuss problems with a common context; communicate on a common ground; collaboration readiness; technology readiness; coupling of work; contribute to the team experience.
Horváth (2012)	Employ smart support of process control systems; allow for the mining of information; support knowledge elicitation methods; support intelligent asset management; integrate 3rd party program support e.g. CAD; have an adaptive system interface; allow for model and document sharing; support multi-channel working; support co-creation in smart ways; communication channels; support virtual presence in smart ways.
Iacob (2011)	Display summaries of work completed; have access to view and edit files freely; have freedom to collaborate with whoever is required; give an awareness of other team members work; ranking functionality; allow for annotations on existing artefacts; consistent interface; support device flexibility; allow for everyone to take part at once; support communication through an integrated chat client; support tracking work/versioning of

Author	Factors which influence successful CSCD
	documents; provide a private space to work; employ a mechanism to handle the resources; integrated tagging functionality.
Jinghua et al. (2014)	Ensure work is completed by the most compliment member; support the even distribution of work.
Liu et al. (2014)	Articulate their completed work; give an awareness of team members activities; select appropriate technology or tools.
Luck (2013)	Avoid ambiguous misunderstandings; avoid uncertain misunderstandings.
Pavkovic et al. (2013)	Allow access to information; delegate clear roles and responsibilities; anticipate the needs of other team members; encourage regular project reviews; encourage mutual trust; give a visual overview of tasks; support the autonomy of tasks; support collaboration; reduce technical conflict.
Rapanta et al. (2013)	Encourage knowledge sharing; support human to human connections; implement consistent corporate policies; support small team negotiation cycles; have appropriate training with groupware systems; overcome cultural barriers; overcome language barriers; encourage employees who are unwilling to cooperate; support co-construction activities; encourage employee trust; problems and solutions develop at the same rate and time; reduce file compatibility issues between groupware systems; reduce software incompatibility; be informed of the benefits of groupware.
Shen et al. (2015)	Allow for monitoring of feedback from manufacturing and assembly; use standardised procedures; allow for direct supervision of team members work; encourage mediated coordination; support efficient decision making; predictive behaviour; new strategies for efficient communication (ideas and comments); allow for ease of sharing; allow for the integration of software.

Author	**Factors which influence successful CSCD**
van Dijk and van der Lugt (2013)	Encourage engagement; support single-tasking.
Vyas et al. (2010a)	Incorporate artefacts into the online design space; adapt to the social needs of the designer; artefact-mediated interaction; encourage social flexibility; allow for artefact-mediated interaction; explore creative solutions; utilize spatial resources.
Vyas et al. (2010b)	Cooperate with each other; support creativity; support exploration; support multi-channel communication.
Vyas et al. (2012)	Support innovative thinking; integrate technology into the offline space.
Wangsa et al. (2011)	Support human-computer interactions; overcome boundaries of access; historical development; have an awareness for community differences; have an awareness for cultural differences; have an awareness for environmental differences; communicate context; minimise conflict; be objective oriented; ensure a hieratical structure of activity.
Xie et al. (2010)	Reduce interpersonal barriers; effectiveness of procedure; support the understanding of information; avoid poor communication; accuracy of information; conflicting information; not distort the meaning of the message; assist in overcoming logistic barriers; minimise information overload; ensure completeness of communication; avoid a lack of coordination; act as a gatekeeper to communication channel; act in a timely way; assist in reducing information overload.
Zheng and Feng (2012)	Allow for reflection on customer feedback; allow easy access to product data; support the synchronisation of data.

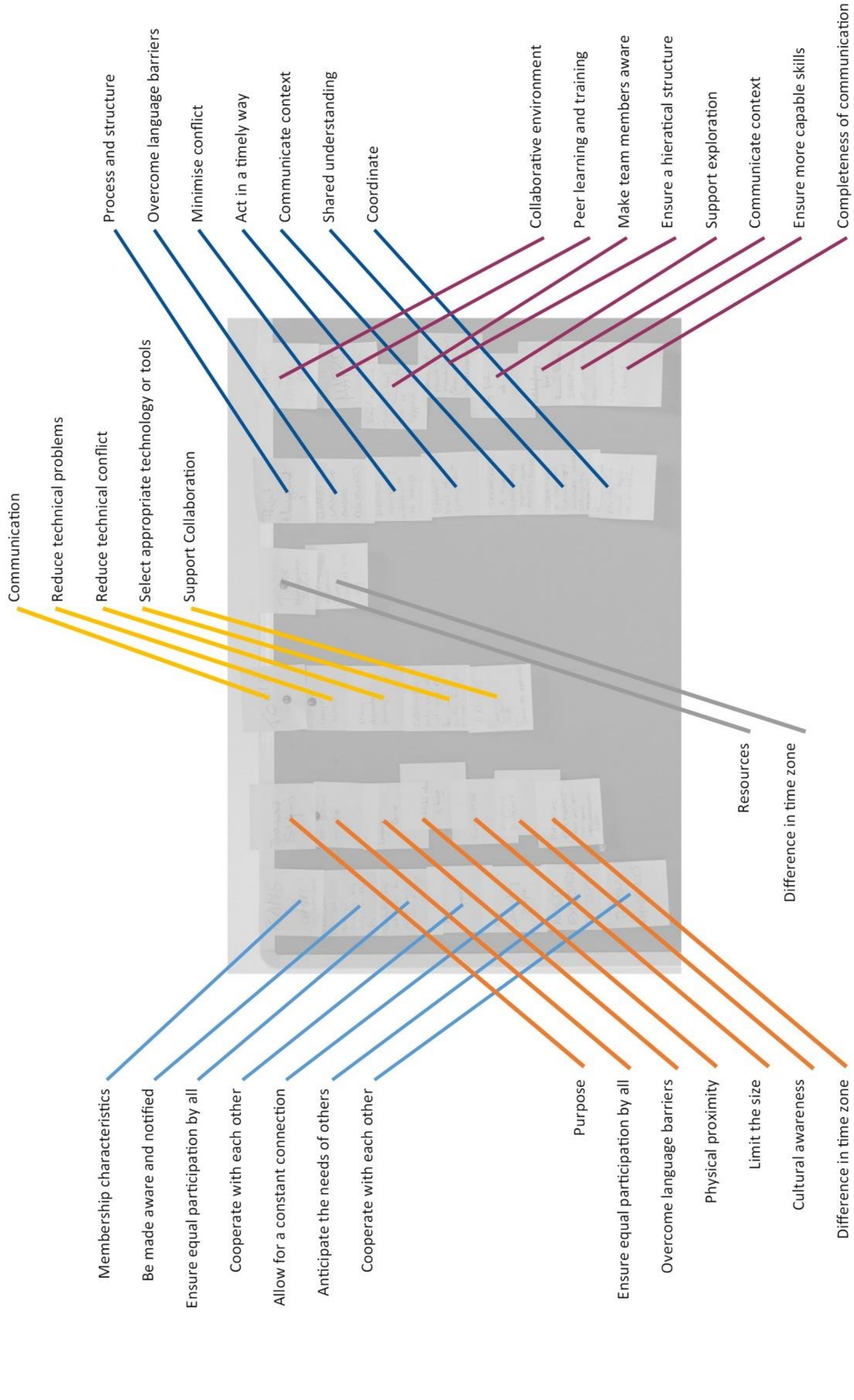
Appendix 5: Technologies identified within the literature

	Pektaş (2015)	Gopsill et al. (2014)	Mamo et al. (2015)	Hurn (2012)	Sheriff (2012)	Lippert et al. (2017)	Sarka et al. (2014)	Shen et al. (2015)	Borsato et al. (2015)
Actify SpinFire								x	
A-Design								x	
Alfresco								x	
Autodesk Streamline								x	
Blog's				x	x		x		
Box			x						
Cimmetry Systems AutoVue								x	
Co-Designer								x	
Collaborative Document Editors					x				
Concept Database								x	
cPLM									x
Cyn.in									x
Dropbox			x						
Elluminate									x
Email		x	x						
ENOVIA MatrixOne								x	
ENOVIA SmarTeam								x	
ENOVIA VPLM								x	
Facebook	x		x	x	x		x		
Flickr							x		

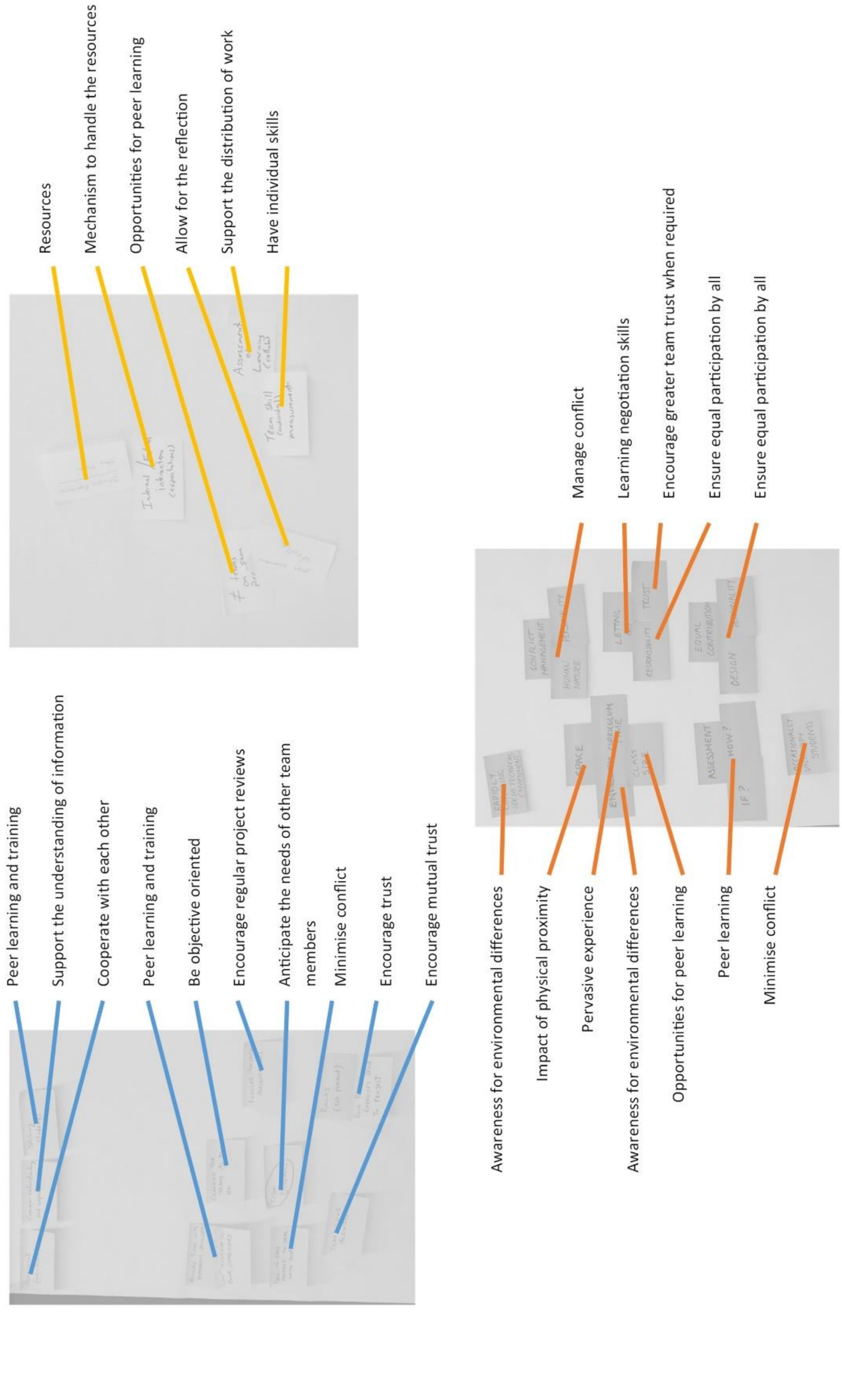
Friend Feed							x		
Google							x		
Google Drive			x			x			
Google Hangouts						x			
Google Wave								x	
ICM								x	
instant messenger					x				
Internal Tools							x		
LinkedIn					x		x		
Lotus Notes								x	
Messenger									x
Microsoft OneNote									x
Microsoft Sharepoint									x
Mindquerry									x
Moodle	x								
Myspace							x		
Nuxeo								x	
One Drive			x						
Oracle Autovue									x
PACT								x	
Partbook		x							
Phone call		x							
Plone									x
PTC Co-Create									x
RealityWave ConceptStation								x	

Second Life							x		
SHARE								x	
SiFAs								x	
Skype	x		x			x	x		x
SMS		x							
Social bookmarking website					x				
SolidWorks eDrawing,								x	
Twitter				x	x		x		
UGS Team Center								x	
VoIP	x								
WhatsApp			x						
Wiki					x				
Wikipedia							x		
Windchill								x	
Xing							x		
Youtube				x			x		
Zotero								x	

Appendix 6: Outcomes of E&PDE 2016 workshop



Appendix 7: Outcomes of ICED 2017 workshop



Appendix 8: Outcomes of DESIGN 2018 workshop

Appendix 9: The full list of top-level categories, sub-categories, requirements for successful CSCD and source of the requirement

Top-level category	Sub-category	Requirement	Source
Communication	Artefacts	Allow response with high quality representation examples	Gopsill et al. (2014)
		Allow for the addition of artefacts to text-based ideation	Herrmann et al. (2013)
		Artefact-mediated interaction	Vyas et al. (2012)
		Incorporate artefacts into the online design space	Vyas et al. (2010)
		Provide an electronic or physical reference for communication	Gopsill et al. (2014)
	Feedback	Allow team members to add comment to past communication	Gopsill et al. (2014)
		Allow team members to define a response to communication	Gopsill et al. (2014)
		Allow for reflection on customer feedback	Zheng & Feng (2012)
		Allow for feedback on ideas	Fruchter et al. (2010)
		Allow for monitoring of Feedback from manufacturing and assembly	Shen et al. (2015)
	Social	Adapt to the social needs of the designer	Vyas et al. (2010)
		Display summaries of work completed	Iacob (2011)
		Allow for Serendipitous Communication	Borsato et al. (2015)

		Encourage knowledge sharing	Rapanta et al. (2013)
		Encourage networking	Borsato et al. (2015)
		Enhance interpersonal skills	Cho & Cho (2014)
		Support human computer interactions	Wangsa et al. (2011)
		Support human to human connections	Rapanta et al. (2013)
		Convey individual personality	Bittner & Leimeister (2013)
		Encourage synergy of team	Antunes et al. (2011)
		Reduce Interpersonal barriers	Xie et al. (2010)
		Encourage social flexibility	Vyas et al. (2012)
		Encourage team familiarity	Bittner & Leimeister (2013)
Environment	Access to Information	Allow access to edit documents	Herrmann et al. (2013)
		Allow access to information	Pavkovic et al. (2013)
		Overcome boundaries of access	Wangsa et al. (2011)
		Have access to view and edit files freely	Iacob (2011)
	Corporate Structure	Use standardised procedures	Shen et al. (2015)
		Historical Development	Wangsa et al. (2011)
		Implement consistent corporate policies	Rapanta et al. (2013)
		Organisational culture	Bittner & Leimeister (2013)
		Have freedom to collaborate with whoever is required	Iacob (2011)
		Seek input from parties outside the design team	Gopsill et al. (2014)

		Effectiveness of procedure	Xie et al. (2010)
		Accept a sense of lack of control	Cho & Cho (2014)
		Support small team negotiation cycles	Rapanta et al. (2013)
		Delegate clear roles and responsibilities	Pavkovic et al. (2013)
		Authority	Bittner & Leimeister (2013)
		Have appropriate training with groupware systems	Rapanta et al. (2013)
Membership Characteristics	Commonality	Difference in time zone	Hirlehei & Hunger (2011)
		Have a cultural awareness for distributed team members	Hirlehei & Hunger (2011)
		Overcome cultural barriers	Rapanta et al. (2013)
		Overcome language barriers	Rapanta et al. (2013)
		Have an awareness for community differences	Wangsa et al. (2011)
		Have an awareness for cultural differences	Wangsa et al. (2011)
		Have an awareness for environmental differences	Wangsa et al. (2011)
		Have an understanding for the impact of physical proximity	Bittner & Leimeister (2013)
	Motivation	Encourage team members through gamification	Herrmann et al. (2013)
		Encourage employees who are unwilling to cooperate	Rapanta et al. (2013)
		Encourage engagement	van Dijk & van der Lugt (2013)

		Be incentivised in their work	Bittner & Leimeister (2013)
		Be provide with positive reinforcement to encourage Information flow	Antunes et al. (2011)
		Be encouraged to have a long-sustained interest in the project	French et al. (2016)
		Support resolution of discussions	Fruchter et al. (2010)
		Be in good morale	Bittner & Leimeister (2013)
	Shared understanding	Support a pervasive experience	Borsato et al. (2015)
		Present information in an easy to understand way	Fruchter et al. (2010)
		Allow the ability to define the purpose of a conversation	Gopsill et al. (2014)
		Avoid ambiguous misunderstandings	Luck (2013)
		Articulate their completed work	Liu et al. (2014)
		Allow for clarification of a statement	Fruchter et al. (2010)
		Discuss problems with a common context	Hirlehei & Hunger (2011)
		Communicate on a common ground	Hirlehei & Hunger (2011)
		Communicate context	Wangsa et al. (2011)
		Support contextualisation over distance	Antunes et al. (2011)
		Support contextualisation with relationships	Antunes et al. (2011)
		Allow for explanation of a statement	Fruchter et al. (2010)

		Share a global view in the aid of a shared understanding	Antunes et al. (2011)
		Avoid miscommunication	Cho & Cho (2014)
		Avoid uncertain misunderstandings	Luck (2013)
		Support the understanding of information	Xie et al. (2010)
	Team Cooperation	Anticipate the needs of other team members	Pavkovic et al. (2013)
		Make team members aware of work	Borsato et al. (2015)
		Be made aware and notified	Herrmann et al. (2013)
		Be made awareness of other team member's actions	French et al. (2016)
		Give an awareness of other team members work	Iacob (2011)
		Give an awareness of team members activities	Liu et al. (2014)
		Allow for direct supervision of team members work	Shen et al. (2015)
		Encourage mediated coordination	Shen et al. (2015)
		Encourage regular project reviews	Pavkovic et al. (2013)
		Allow for shared visualisation of work	Benolken et al. (2010)
		Cooperate with each other	Vyas, Nijholt, Heylen, et al. (2010)
		Support co-construction activities	Rapanta et al. (2013)
		Allow for a constant connection	French et al. (2016)
		Avoid poor communication	Xie et al. (2010)
		More opportunities for peer learning and training	French et al. (2016)

		Cooperate with each other	Borsato et al. (2015)
		Greater retention of learning	French et al. (2016)
		Ensure equal participation by all	Cho & Cho (2014)
	Trust	Accuracy of information	Xie et al. (2010)
		Conflicting information	Xie et al. (2010)
		Not distort the meaning of the message	Xie et al. (2010)
		Minimise conflict	Wangsa et al. (2011)
		Encourage employee Trust	Rapanta et al. (2013)
		Encourage greater team trust when required	French et al. (2016)
		Encourage mutual trust	Pavkovic et al. (2013)
Process and Structure	Decision Making	Ranking functionality	Iacob (2011)
		Support efficient decision making	Shen et al. (2015)
		Allow for greater opportunities to express opinions	Cho & Cho (2014)
		Allow for improved decision making	French et al. (2016)
		Learning negotiation skills	Cho & Cho (2014)
		Allow for negotiation	Fruchter et al. (2010)
	Knowledge Capture	Allow for annotations on existing artefacts	Iacob (2011)
		Allow for artefact-mediated interaction	Vyas et al. (2012)
		Allow for the capture of high-quality representation of artefacts	Gopsill et al. (2014)
		Allow for the capture of meeting information	Gericke et al. (2010)

			Allow for the documenting of decisions	Hansen & Dalsgaard (2012)
			Allow for the recording of modifications to the artefact	Gopsill et al. (2014)
			Allow for text-based description	Gopsill et al. (2014)
			Allow for the asking of closed questions	Fruchter et al. (2010)
			Record and capture the focus of the conversation	Gopsill et al. (2014)
		Productivity	Greater likelihood of catching mistakes	French et al. (2016)
			Allow for the reflection on work and decisions	Hansen & Dalsgaard (2012)
			Collaboration readiness	Hirlehei & Hunger (2011)
			Technology Readiness	Hirlehei & Hunger (2011)
			Faster design through collaboration	French et al. (2016)
			Limit the size of the response	Gopsill et al. (2014)
			More thorough outputs	Cho & Cho (2014)
			Be objective oriented	Wangsa et al. (2011)
			Performance (Quantity of output)	Bittner & Leimeister (2013)
			Reduced rework time	French et al. (2016)
			Ensure work is completed by the most compliment member	Jinghua et al. (2014)
			Assist in overcoming logistic barriers	Xie et al. (2010)

		Coupling of work	Hirlehei & Hunger (2011)
		Ensure efficiency in communication	Cho & Cho (2014)
		Predictive behaviour	Shen et al. (2015)
		Productivity	Cho & Cho (2014)
		Assist in the reduction of iterative loops	Bittner & Leimeister (2013)
		Assist in the reduction of rework	Bittner & Leimeister (2013)
		Support the reuse of data	Gericke et al. (2010)
		Support rework after the fact	Herrmann et al. (2013)
		Support single tasking	van Dijk & van der Lugt (2013)
		Support group member satisfaction	Bittner & Leimeister (2013)
Resources	Competency	Minimise information overload	Xie et al. (2010)
		Ensure completeness of communication	Xie et al. (2010)
		Include the ability to conclude a conversation thread	Gopsill et al. (2014)
		Enhance communication skills	Cho & Cho (2014)
		Have a diverse range of skills	Bittner & Leimeister (2013)
		Have individual skills	Bittner & Leimeister (2013)
		Ensure more capable employee skills	Cho & Cho (2014)
		Contribute to the team experience	Hirlehei & Hunger (2011)

Coordination	Provide a private space to work	Iacob (2011).
	Allow for the organisation of communication by grouping	Gopsill et al. (2014)
	Give a visual overview of tasks	Pavkovic et al. (2013)
	Allow for the response to be coordinated to the correct purpose	Gopsill et al. (2014)
	Avoid a lack of coordination	Xie et al. (2010)
	Employ a mechanism to handle the resources	Iacob (2011).
	Coordination	Borsato et al. (2015)
	Coordination	Bittner & Leimeister (2013)
	Act as a gatekeeper to communication channel	Xie et al. (2010)
	Ensure a hieratical structure of activity	Wangsa et al. (2011)
	Support the organisation of Meetings	Benolken et al. (2010)
	Assist in negating scheduling problems	Fruchter et al. (2010)
	Employ smart support of process control systems	Horváth (2012)
	Act in a timely way	Xie et al. (2010)
	Support an aligning effort of their team members	Hansen & Dalsgaard (2012)
	Problems and olutions develop at the same rate and time	Rapanta et al. (2013)
	Support the even distribution of work	Jinghua et al. (2014)

Innovation	Explore creative solutions	Vyas et al. (2012)
	Support creativity	Vyas, Nijholt, Heylen, et al. (2010)
	Support easy switching between ideation topics	Herrmann et al. (2013)
	Support exploration	Vyas, Nijholt, Heylen, et al. (2010)
	Support innovation	Bittner & Leimeister (2013)
	More creative outputs	Cho & Cho (2014)
	Performance (Quality of output)	Bittner & Leimeister (2013)
	Support the rapid transformation of ideas	Hansen & Dalsgaard (2012)
	Support innovative thinking	Vyas, Nijholt & van der Veer (2010)
	Support exploration	Fruchter et al. (2010)
	Support problem solving	Fruchter et al. (2010)
Knowledge Management	Integrated tagging functionality	Iacob (2011).
	Allow for the categorisation of communication	Gopsill et al. (2014)
	Allow for referencing previous communication	Gopsill et al. (2014)
	Allow for organisation of communications	Gopsill et al. (2014)
	Allow for the mining of information	Horváth (2012)
	Support knowledge elicitation methods	Horváth (2012)

		Support Intelligent asset management	Horváth (2012)
		New Strategies for efficient communication (ideas and comments)	Shen et al. (2015)
		Support the autonomy of tasks	Pavkovic et al. (2013)
		Allow for easy linking between communications	Gopsill et al. (2014)
		Assist in reducing information overload	Xie et al. (2010)
		share a global view to reduce information overload	Antunes et al. (2011)
	Managing the Sharing of Data	Integrate 3rd party program support e.g. CAD	Horváth (2012)
		Allow easy access to product data	Zheng & Feng (2012)
		Reduce file compatibility issues between groupware systems	Rapanta et al. (2013)
		Reduce software incompatibility	Rapanta et al. (2013)
		Have an adaptive system interface	Horváth (2012)
		Consistent interface	Iacob (2011)
		Reduce complexities whilst sharing data	French et al. (2016)
		Integrate technology into the offline space	Vyas, Nijholt & van der Veer (2010)
		Allow for ease of sharing	Shen et al. (2015)
		Allow for model and document sharing	Horváth (2012)
		Support the synchronisation of data	Zheng & Feng (2012)
		Integrate with data storage systems	Gericke et al. (2010)
		Support device flexibility	Iacob (2011)

		Allow for the integration of software	Shen et al. (2015)
		Allow for pushing of information	Gopsill et al. (2014)
		Support tracking work / versioning of documents	Iacob (2011)
		Be informed of the benefits of groupware	Rapanta et al. (2013)
		Support the answering of multiple threads through a single response	Gopsill et al. (2014)
		Support multi-channel working	Horváth (2012)
		Support co-creation in smart ways	Horváth (2012)
	Communication	Support synchronous working with live documents	Herrmann et al. (2013)
		Allow for everyone to take part at once	Iacob (2011)
		Select appropriate technology or tools	Liu et al. (2014)
		Support Collaboration	Pavkovic et al. (2013)
		Support Collaboration	Borsato et al. (2015)
		Support multi-threading conversations	Gopsill et al. (2014)
		Support audio and video conferencing	Benolken et al. (2010)
		Communication Channels	Horváth (2012)
		Support communication	Bittner & Leimeister (2013)
		Allow for messenger style communication	Benolken et al. (2010)
		Support multi-Channel Communication	Vyas, Nijholt, Heylen, et al. (2010)
		Support the proposition of design change	Hansen & Dalsgaard (2012)

		Support virtual presence in smart ways	Horváth (2012)
		Support communication through a integrated chat client	Iacob (2011)
		Support design change	Hansen & Dalsgaard (2012)
		Reduce technical conflict	Pavkovic et al. (2013)
		Reduce technical problems	Fruchter et al. (2010)
		Utilize spatial resources	Vyas et al. (2012)
		Reduce difficulties in coordination due to technical difficulties	Antunes et al. (2011)

Appendix 10: Statements from students' reflective reports between 2015 and 2017 used in coding

Code	**Statements from students' reflective reports**
R15-1	Preparation of the prototype required a high level of communication and team members to act proactively.
R15-2	Multi-threaded communication provided structure to conversations.
R15-3	Asynchronous communication acted synchronously in situations when required.
R15-4	Communication of the process and required detail of design activity outcomes.
R15-5	It was difficult to convey to distributed team members that design is not a fixed process and to be successful there had to be some experimentation with other methods.
R15-6	Breakdown in communication cost the team time and created unease between team members.
R15-7	Social network sites offer a less formal place to discuss potential work and to share experiences.
R15-8	There is a precedence to think that Email is a professional and formal tool for official communications.
R15-9	Team employed gatekeepers to ensure communication between and across teams was full and rich.
R15-10	Team members who engaged more were deemed as more compliant.
R15-11	Proactive team members were perceived as more competent.
R15-12	Team members are unaware of other skills and if they are capable of completing tasks to a suitable quality.
R15-13	Team members disregarded agreed work and focused on tasks which contribute to their personal goals.
R15-14	The team split tasks into sub-groups, two local and one distributed.

R15-15	Teams discussed using Trello to coordinate work.
R15-16	Prototyping required more discussion during video conferences to decide how data would be shared and how feedback would be received.
R15-17	Team members split tasks based on their skills.
R15-18	Multi-threaded communication enabled multiple conversations at once.
R15-19	Lack of communication during the detailed design stage adversely affected the teams working dynamic and morale.
R15-20	Form of the product was discussed on messenger live.
R15-21	Posting concept ideas onto Facebook for discussion.
R16-1	Team members mostly conducted design tasks asynchronously.
R16-2	A range of skills and expertise were required to complete tasks at different stages of the design process.
R16-3	Team members inexperienced in design struggled to share initial concept ideas and instead produced well developed concepts.
R16-4	Team members worked interdependently when required especially for more complex tasks.
R16-5	Asynchronous methods instinctively took longer to conduct.
R16-6	Local team members utilised excel to conduct a rating a weighting exercise which was asynchronously checked by other distributed team members.
R16-7	Using a messenger chat and live editing documents, distributed team members contributed to a distributed weighting and rating exercise by sharing their opinions on the weighting and the scores granted.
R16-8	Team members were unsure how to apply their knowledge of co-located design practice to a distributed setting. They struggled to identify concept selection techniques which could be suitable using video conferencing.

R16-9	6-3-5 method was conducted over one week using cloud storage and messenger.
R16-10	A brainstorming session was conducted during a video conference.
R16-11	Non designers struggle to follow complex innovative thinking design tasks.
R16-12	Its difficult to conduct design activities over skype in real time and so local teams conducted the activities distributed.
R16-13	When focused on short tasks productivity was high.
R16-14	Sketching digitally live helped with the understanding of concepts.
R16-15	Digital sketches were difficult to annotate restricting the understanding of concepts.
R16-16	Lack of annotations impacted the understanding of a concept.
R16-17	Sharing live documents ensured up to date knowledge on the progress of the project and faster turnaround of design activities.
R16-18	Teams uploaded scans to Facebook to enable concept evaluation.
R16-19	Teams posted their findings from research on Facebook
R16-20	Team members shared the outcomes of their design activities.
R16-21	Team members shared their ideas by 3D printing simple low-cost geometries of product forms to demonstrate how the user might interact with the product.
R16-22	Facebook was used to conduct ice breaker activities.
R16-23	Teams used video conference to conduct an ice breaker meeting where team members introduced themselves and their interest in taking part in the project.
R16-24	Teams members took part in a distributed ice breaker to build interpersonal relationships.
R16-25	Greater social communication leads team members to trust others with more complex design tasks.

R16-26	Team building exercises sharing their personalities and sketching together contributed to a shared sense of trust.
R16-27	Disagreements between team members were caused by cultural differences when voting was employed. Team members disagreed on with a unanimous or majority vote was required.
R16-28	The team used a messenger app to facilitate distributed decision making using voting functionality for semi-synchronous communication.
R16-29	Voting mechanism employed on messenger
R16-30	Voting on Facebook made decision making democratic.
R16-31	Team members took part in a distributed voting activity where they shared rationale on decisions made.
R16-32	A pole can be created within Facebook messenger to reach a consensus.
R16-33	A voting mechanism was used to find a suitable time for regular meetings.
R16-34	Voting mechanisms were a powerful decision-making tool for qualitative decisions.
R16-35	Facebook makes it easy to search and find files using the search functionality within a group.
R16-36	Facebook made team members accountable for what they said they would achieve.
R16-37	Google docs enabled simultaneous working.
R16-38	Google Docs enabled all team members to share data live.
R16-39	Easy access to documents made working asynchronously easier.
R16-40	Files hosted on Facebook were available to all team members.
R16-41	Google drive permits us to share drawings using a mobile device. Everybody could quickly and easily view, print and review.

R16-42	less files were sent during the prototyping stage due to the nature of the file format.
R16-43	Facebook was an efficient means of sharing documents and arranging meetings.
R16-44	Facebook groups acted as a summary of meetings for those who could not attend.
R16-45	The team used regular summaries on social network sites to ensure they agreed and everyone was up to date.
R16-46	A shared product design specification document on cloud storage allowed all to be aware and to update the progress of the product.
R16-47	Teams used a shared doc that everyone could edit to find a meeting date and time.
R16-48	A coordination document was kept on cloud storage to note project decisions.
R16-49	Cloud storage enabled versioning to ensure only one document existed.
R16-50	The team used google docs to assign tasks.
R16-51	When team members conducted work without checking the coordination document context was lost and work was not up to a competent standard.
R16-52	Team members did not share their progress in an appropriate way and work had to be redone to fit.
R16-53	Messenger for organisation and social network sites for storing data and decisions.
R16-54	Documenting decision was important to ensure the project progressed.
R16-55	Team members would share work on Facebook, receive feedback and iterate.
R16-56	Sketches uploaded to google drive for storage and retrieval later.

R16-57	Teams uploaded the results of their morphological charts to cloud storage for easy access.
R16-58	The team used google docs to record task outcomes.
R16-59	Teams discussed using Trello as a tool to capture the decision-making process.
R16-60	Using mobile devices as a supplementary screen for coordination during a video conference meeting. Almost to take live meeting minutes.
R16-61	Collocated teams using paper to communicate and digital sketching tools for distributed teams.
R16-62	Paper based sketching techniques were easy to conduct asynchronously but difficult to share.
R16-63	Wikis were used to store data from activities and share and organise knowledge.
R16-64	Box for documents.
R16-65	Sensitive information can be securely stored on cloud storage.
R16-66	Cloud storage acted as a repository to store and manage data requirements.
R16-67	Easy access to well labelled documents enabled faster working turnarounds.
R16-68	Cloud storage held older documents which were mistaken from newer documents causing rework.
R16-69	Cloud documents were often overwritten confusing team members.
R16-70	Messenger was difficult to manage team members and knowledge as it kept getting lost.
R16-71	Slack worked as a KM tool to note objectives and track work.
R16-72	Trello provided visible task allocations.

R16-73	Miscommunication of document location caused delays in the design process.
R16-74	Teams used cloud storage as a communication and easy to access space to easily access and talk about morphological charts during video conference.
R16-75	Utilising cloud storage, team members could share documents in real time.
R16-76	Sketching digitally reduced complexities digitising data.
R16-77	High quality scanners retained more detail of a sketch compared to a photograph.
R16-78	Meeting minutes act as a summary for team members who could not attend meeting.
R16-79	The majority of files were stored on cloud storage, but this didn't account for all files.
R16-80	Google docs for live sharing documents.
R16-81	Team members scanned sketches for high quality digital artefacts to share over Facebook.
R16-82	Facebook was used to share documents.
R16-83	Facebook was used to share data.
R16-84	Team documents were exchanged on Facebook.
R17-1	Working asynchronously fitted students schedules best.
R17-2	Team leaders on Facebook reduced confusion and conflict.
R17-3	Team members are despondent to change and want to stick with what they know.
R17-4	Team employed gatekeepers in each country to be responsible for updates.
R17-5	Local project leaders delegated tasks.
R17-6	Team leaders in each location acted as gatekeepers for sub teams.

R17-7	Teams have the opportunity to explore CSCD technologies during the global design project. But teams missed the requirement to discuss what they are willing to use for the next 12 weeks.
R17-8	Due to the popularity of Facebook, team members were aware of how to use it.
R17-9	Video conferencing facilitated design activities to send and receive documents.
R17-10	Team members did not explore and solve their teamwork issues themselves contributing to their learning but relied on lecturers and mentors to suggest solutions.
R17-11	Sharing google hangouts link on social network site for easy access.
R17-12	Team made the decision to stop using multiple technologies and instead focus on using one Facebook group to coordinate work.
R17-13	Facebook was utilised for arranging meetings.
R17-14	Team members found it difficult to arrange a regular meeting time due to their existing schedules.
R17-15	Team members did not progress the project with the design requirements. Time restrictions of the project and the advice of lecturers and mentors instead drove the progress.
R17-16	Visuals were required in addition to descriptions to feed understanding and enable decision to be made.
R17-17	Teams who utilised only asynchronous design techniques and produced the lowest number of concepts.
R17-18	Too many tools were adopted by a team and decisions were being lost and documents cannot be found.
R17-19	Team members reported messages going missing on messenger.
R17-20	Information can be lost when using multiple platforms.
R17-21	Difficult to switch technologies after work has already been invested in one. Then testing and selection from the start is required.

R17-22	Team members feel motivated to take part in the project when they can trust others.
R17-23	Team members felt more motivated towards the end of the project as they had a clear goal to work towards.
R17-24	Facebook is pervasive with student groups.
R17-25	Google Calendar was used to note busy times for each team member and find a suitable weekly video conference time.
R17-26	Perception that phones offer simpler interfaces than desktop / laptop devices.
R17-27	Asynchronous tasks restricted the turnaround time.
R17-28	Team members may have benefited from sharing skills rather than focusing on location based coordination.
R17-29	When synchronicity is not required higher quality outcomes can emerge.
R17-30	Asynchronous working over a social network site cause misunderstanding.
R17-31	Sharing links to websites which explain the rationale of design activities help team members trained in other disciplines to relate to the process.
R17-32	Describing concepts was difficult but a sketch helped to contextualise the idea.
R17-33	An animation of a CAD file communicated how a product functioned.
R17-34	Facebook supported social communication.
R17-35	A Facebook that was separate from social or the ability to turn off social when work is required.
R17-36	Team members connected on Facebook to socialise but intend to keep project communication separate using google hangouts.
R17-37	Team members used email to make an initial connection but quickly switched to Facebook for the remaining project communication.

R17-38	More social communication between local teams.
R17-39	Social communication took away some time from project work.
R17-40	Team members built trust through social interactions.
R17-41	Teams members took part in a distributed ice breaker using Hofstede's dimensions to build interpersonal relationships.
R17-42	More cultural similarities with London team building trust.
R17-43	Social communication helped to build relationships between team members.
R17-44	Team members built trust through social interactions.
R17-45	Teams members took part in a distributed ice breaker using Hofstede's dimensions to build interpersonal relationships.
R17-46	Distributed team members have increased contact during collaborative work leading to greater trust.
R17-47	Higher levels of messages are perceived as higher levels of trust.
R17-48	Ice breaker exercises helped to build trust through sharing informal information.

Appendix 11: Statements from class diaries between 2015 and 2017 used in coding

Code	Statements from class diaries
D15-1	Messenger was used to inform team members where they can access documents.
D15-2	Language difference caused barriers during video conference. Social network sites being text based helped to overcome these issues.
D15-3	When video conferencing broke, teams turned to voice memos to summarise completed work in a semi synchronous method of communication. Allowing for longer and more personalised messages compared to text-based communication.
D15-4	Facebook overcame boundaries of geography and time difference to enable communication.
D15-5	Distributed team members from multidisciplinary backgrounds did not share the same knowledge of design activities. To ensure all were informed of the procedure of an activity and happy to use this, the team communicated on Facebook messenger and a voting functionality.
D15-6	Conception that replying outside regular business times is laziness or lack of interest in project.
D15-7	Different cultures took silence to mean different things. Platforms should encourage a response.
D15-8	Skype encountered a connectivity issue during a design activity and the team could not resolve the problem. The team switched to a text based messenger to complete the task.
D15-9	Students used messenger chat on mobile as its fast and responsive.
D15-10	WhatsApp was used for informal communication.
D15-11	WhatsApp was used as a synchronous communication method for rapid responses.

D15-12	Teams can become less productive if information is repeated in messenger.
D15-13	Facebook for asynchronous.
D15-14	Facebook was chosen as the main method of communication.
D15-15	Facebook was visible to all and provided rapid communication.
D15-16	Facebook offers quick responses and prompt feedback in a central location.
D15-17	Facebook messenger is a slower method of communication than a face to face conversation.
D15-18	Facebook was used as a asynchronous communication to update team members.
D15-19	Students choose Facebook messenger as it was the technology most were familiar with.
D15-20	Skype for synchronous.
D15-21	Through a discussion with distributed team members, students decided to use google hangouts as the primary method of communication.
D15-22	Teams members took part in a distributed ice breaker to test communication methods.
D15-23	When the quality of a video conference chat degraded the team switched to a text based chat which became the primary communication method moving forward.
D15-24	During design tasks their was high levels of communication before and after but little whilst the activities were being conducted.
D15-25	Multiple channels were used to compartmentalise communications.
D15-26	Discussion involving all team members took significantly longer synchronously.
D15-27	Discussion asynchronously required less messages as their was more agreement.

D16-1	Facebook offers a mix of formal and informal information.
D16-2	Google Hangouts allowed team members to share information with each other when discovered.
D16-3	Students feel demotivated as they struggle with language barriers and confidence speaking in a second language.
D16-4	Distributed team members did not contribute to ideation tasks feeling it was not their expert area and contributed more to product development discussions.
D16-5	Messenger is more instantaneous than social network sites.
D16-6	Messengers used for local communication where fast responses are required.
D16-7	Messenger allows for updating on the go. Convenient for the sender and the receivers.
D16-8	Teams discussed using Trello to improve the productivity of teams.
D16-9	Facebook enabled the sharing of sketches and comments contextualised the concepts.
D16-10	Concepts were linked to the decisions made to develop them to give context.
D16-11	Team members were unsure if their design activity instructions had been understood as little feedback was given from distributed team members.
D16-12	It was difficult to help distributed team members understand that design is not a fixed process and to be successful their had to be some experimentation with other methods.
D16-13	Teams discussed how they will share data for the remainder of the project during a video conference. Cloud storage is being investigated.
D16-14	Communication breakdown has resulted in team members lack of trust for distributed team members.
D16-15	For communicating, synchronous tools were preferred.

D16-16	Team members inexperienced with ideation found it easier to develop products rather than in the generation of new ideas. AR supported this development process by allowing distributed team members to see the products in a real world environment.
D16-17	Teams discussed the CAD model development using screen sharing during a video conference.
D16-18	Utilising the whiteboard functionality of skype to collaboratively draw during a video conference meeting.
D16-19	Screen sharing was useful on video conferencing to understand others ideas.
D16-20	Augmented reality using CAD files helped to contextualise the size and function of the product.
D16-21	Utilising the whiteboard functionality of skype to annotate on other images during a video conference meeting.
D16-22	The teams prepared simple prototypes (Paper and card models) to share ideas and images over a shared Facebook group. Teams rationalised the development of these prototypes from this discussion.
D16-23	Team members inexperienced with ideation struggled to utilise sketching in this process. Team members drew existing products rather than potentially new ideas.
D16-24	Google hangouts was used to facilitate design activities.
D16-25	Google hangouts was used as a synchronous communication method for discussing concept ideas.
D17-1	Google Hangouts allowed team members to share information with each other when discovered.
D17-2	Paper sketches from a design activity were shared digitally.
D17-3	Some methods for storing and sharing documents may not be appropriate for business uses.
D17-4	An app was used to scan and share sketched images.

D17-5	Team members experienced no issues of trust, supported by a high level of data storage and easy access due to a data storage procedure.
D17-6	Teams can share various information such as documents, picture, video, weblinks, technical files and zip folder without any expense.
D17-7	Physical documents were scanned and uploaded to cloud storage.
D17-8	Incompatibility of CAD files between teams restricted which data could be shared.
D17-9	Teams need to avoid sharing unproductive information.
D17-10	Some team member who were unfamiliar with Google hangouts and messengers in general struggled to learn how to utilise functionality such as sharing photos.
D17-11	Student tested how the instant messenger functionality of Google hangouts app affords them to share photos for project work and informal communication.
D17-12	Team members experienced no issues of trust was supported by data storage procedures implemented in week one.
D17-13	For sharing and storing asynchronous tools were preferred.
D17-14	To ensure team members working asynchronously are aware, post can be starred or pinned to ensure everyone is aware.
D17-15	Facebook allowed team members to comment on sketches, sharing essential feedback.
D17-16	Hashtags made it easy to tag information with stages of the design process in slack.
D17-17	Slacks channels feature enabled multiple channels for sections of the project or sub teams.
D17-18	Facebook connects all team members and keeps them aware through notifications.
D17-19	Team members who do not regularly use Facebook did not receive notifications and are not always aware of the latest communications.

D17-20	Team members who are not continuously connected online to Facebook may miss communications and schedules for future meetings.
D17-21	Awareness of the progress of the project contributed to faster design activities.
D17-22	A communications manager ensured speedy responses and enforced procedures.
D17-23	Team members can remove themselves from being notified of certain conversation which are not relevant to them on social network sites.
D17-24	Team management groupware assisted in ensuring all team members are aware of the progress of a project.
D17-25	When students didn't reply in a timely manor on messenger they were perceived as unreliable.
D17-26	When students were constantly available on messenger they were considered reliable.
D17-27	Missed notifications through the use of slack as it is not integrated with daily life.
D17-28	Messenger was useful for reminding team members of meetings or work.
D17-29	The project was delayed by not communicating that work was complete and uploaded to google docs.
D17-30	Team members shared feedback on the progress of the design activity synchronously using video conferencing and asynchronously using the Facebook messenger app.
D17-31	Hyperlinks connected documents with visible posts on groupware.
D17-32	Reposting links on messenger informed team members and motivated them to contribute in response.
D17-33	Cloud storage solutions did not notify team members of new documents or changes to documents.

D17-34	Team members struggled to give their opinion during video conference meetings due to lack of confidence.
D17-35	Cultural differences made it difficult to communicate a point. Video conference assisted in allowing for visual communication and gestures.
D17-36	Video conference allowed disagreements to be overcome and conflict is contained.
D17-37	Google Hangouts is a better system for dealing with multiple participants.
D17-38	Video conferencing overcame barriers of confusion caused by text based communication.
D17-39	Skype was used to make decision on project execution.
D17-40	Teams discussed how they will communicate for the remainder of the project during a video conference. A synchronous and a synchronous method is being investigated.
D17-41	Team members communicated product geometry and size using 3D printed models and video conferencing.
D17-42	During a video conference, Technological issues lead to miscommunication of information and work being completed incorrectly.
D17-43	To be effective, video conference meetings must include all team members.
D17-44	It was necessary to ensure team members have regularly scheduled video conference meetings to keep productivity.
D17-45	When bidding for work during a video conference it is difficult to know which team member is most suitable.
D17-46	Team members did not do assigned tasks and this was not discovered until weakly video conference meeting.
D17-47	Tasks were assigned at a video conference based on skills of the team members.

D17-48	After feedback from all team members on video conference, decision were made.
D17-49	Through video conferencing all team members were connected to discuss problems and make decisions.
D17-50	Team members felt Facebook messenger was limiting the sharing of rationale and video conference was essential in addition to question each other decisions.
D17-51	During a video conference one team member summarised the ideas of the team on a whiteboard with a second camera pointed towards the whiteboard.
D17-52	Team members found it easier to discuss ideas synchronously on video conference than text based.
D17-53	The team who utilised only synchronous design techniques achieved the highest number of concepts.
D17-54	It was difficult to share sketches over video conference.
D17-55	Webcams were useful for capturing and sharing sketching data but ambiguity required explanation on video conferencing.
D17-56	During video conferencing it was difficult to document visuals such as demonstrating prototypes and interactions. Screenshots were used to record this for reuse and to document team members reactions.
D17-57	Teams discussed how they will document decisions for the remainder of the project during a video conference. Decision making procedures are being investigated.
D17-58	Difficult to display work on a physical whiteboard with distributed team members and video conferencing.
D17-59	Sharing images of sketches during a video conference meeting on mobile devices over messenger.
D17-60	Video conferencing and discussions helped to clarify information and ensure a shared understanding.

D17-61	Whiteboards combined with video conferencing enabled speech and visual communication to support understanding.
D17-62	The distributed nature of the projects was supported by face to face communication which could help with understanding.
D17-63	Team members showed their sketches to the webcam during video conference meetings.
D17-64	Team members felt a lack of trust because of the lack of face to face interactions.
D17-65	Through a discussion with distributed team members, google drive was selected as the cloud storage solutions enabling 'integration with google hangouts and google docs'.
D17-66	Facebook was accessible by all.
D17-67	Offline, team members were making plans to socialise before the beginning of the project and to have a social activity with distributed team members online.
D17-68	Using email to share contact details on other platforms.
D17-69	Email was used as an introductory technology to share profiles and communication information.
D17-70	Facebook was used to share the results of design activities sharing scanned images.
D17-71	Google hangouts allowed team members to share formal project information.

Appendix 12: Disagreements on the coding of sentences

	Technology			Functionality			Requirements		
	Coder 1	Coder 2	Coder 3	Coder 1	Coder 2	Coder 3	Coder 1	Coder 2	Coder 3
R17-32									
D17-35				Video Conferencing	Conversation Tools		Commonality	Communication	Overcome boundaries c
R17-6							Company Structure		Managing the sharing o
R16-55				Shared File Repositorie	Group Dynamics Tools		Feedback		A shared understanding
R16-39				Shared File Repositorie	Group Dynamics Tools		Access to information	Greater productivity	Managing the sharing o
D17-14							Commonality	A shared understandin	Knowledge manageme
D16-7				Conversation Tools	Conversation Tools	Syndication Tools	Productivity	Greater productivity	Overcome boundaries c
R16-69				Shared File Repositorie	Shared Editors		Knowledge Manageme	Co-operation	Managing the sharing o
R16-49							Co-ordination		Managing the sharing o
D15-27							Communication	Co-operation	
R17-45						Conversation Tools	Trust	Social communication	Social communication
R17-37									
R16-28				Polling Tools	Polling Tools				
R17-40						Conversation Tools			
R16-26				Group Dynamics Tools		Conversation Tools			
R17-44							Trust	Building of trust	
D16-22				Group Dynamics Tools	Shared File Repositorie	Conversation Tools	Artefact-mediated com	A shared understandin	Building of trust
R16-25							Social communication	Building of trust	Communication
D17-32							Motivation	Greater productivity	Building of trust
R17-47						Syndication Tools	Trust	Building of trust	Knowledge manageme
D15-18				Conversation Tools	Group Dynamics Tools	Shared File Repositories			
R16-38	Collaborative Documer	Cloud Storage		Shared Editors	Shared File Repositories		Sharing Data	Overcome boundaries	Social communication
R15-7							Company Structure		Artefact-mediated com
D17-2							Sharing Data		Co-ordination
R16-1							Communication		A shared understanding
R16-62							Knowledge Capture	Greater productivity	
D16-14				Conversation Tools		Desktop/Application Sharing			
R16-8				Group Dynamics Tools	Video Conferencing		Decision making	Overcome boundaries	Knowledge capture
R17-16							Decision Making	Decision making	Motivation
R16-54				Shared File Repositorie	Group Dynamics Tools		Decision Making		Managing the sharing o
D17-67							Commonality		Feedback mechanisms
R16-59				Shared File Repositorie	Conversation Tools	Conversation Tools			
R16-67				Shared File Repositorie	Group Dynamics Tools		Knowledge manageme	Greater productivity	Building of trust

Appendix 13: Coding of GDP 2015 - 17 data

Code	Technology Relation	Functionality	Requirement
D15-1	Messengers	Conversation Tools	Access to Information
D15-2		Conversation Tools	Commonality
D15-3	Messengers	Conversation Tools	Commonality
D15-4	Social Network Site	Conversation Tools	Commonality
D15-5	Social Network Site	Conversation Tools	Commonality
D15-6		Conversation Tools	Commonality
D15-7		Conversation Tools	Commonality
D15-8		Conversation Tools	Communication
D15-9	Messengers	Conversation Tools	Communication
D15-10	Messengers	Conversation Tools	Communication
D15-11	Messengers	Conversation Tools	Communication
D15-12	Messengers	Conversation Tools	Communication
D15-13	Social Network Site	Conversation Tools	Communication
D15-14	Social Network Site	Conversation Tools	Communication
D15-15	Social Network Site	Conversation Tools	Communication
D15-16	Social Network Site	Conversation Tools	Communication
D15-17	Social Network Site	Conversation Tools	Communication
D15-18	Social Network Site	Conversation Tools	Communication
D15-19	Social Network Site	Conversation Tools	Communication
D15-20	Video Conferencing	Conversation Tools	Communication
D15-21	Video Conferencing	Conversation Tools	Communication
D15-22	Video Conferencing	Conversation Tools	Communication
D15-23	Video Conferencing	Conversation Tools	Communication

D15-24		Conversation Tools	Communication
D15-25		Conversation Tools	Communication
D15-26		Conversation Tools	Communication
D15-27		Conversation Tools	Communication
D16-1	Social Network Site	Conversation Tools	Knowledge Management
D16-2	Video Conferencing	Conversation Tools	Knowledge management
D16-3		Conversation Tools	Motivation
D16-4		Conversation Tools	Motivation
D16-5		Conversation Tools	Productivity
D16-6	Messengers	Conversation Tools	Productivity
D16-7	Messengers	Conversation Tools	Productivity
D16-8	Team Management Groupware	Conversation Tools	Productivity
D16-9	Social Network Site	Conversation Tools	Shared Understanding
D16-10		Conversation Tools	Shared Understanding
D16-11		Conversation Tools	Shared understanding
D16-12		Conversation Tools	Shared understanding
D16-13	Video Conferencing	Conversation Tools	Sharing Data
D16-14		Conversation Tools	Trust
D16-15		Conversation Tools	Trust
D16-16	Video Conferencing	Desktop/Application Sharing	Artefact-mediated communication
D16-17	Video Conferencing	Desktop/Application Sharing	Feedback
D16-18	Video Conferencing	Desktop/Application Sharing	Innovative thinking

D16-19	Video Conferencing	Desktop/Application Sharing	Shared Understanding
D16-20		Desktop/Application Sharing	Shared Understanding
D16-21	Video Conferencing	Desktop/Application Sharing	Sharing Data
D16-22	Social Network site	Group Dynamics Tools	Artefact-mediated communication
D16-23		Group Dynamics Tools	Artefact-mediated communication
D16-24	Video Conferencing	Group Dynamics Tools	Communication
D16-25	Video Conferencing	Group Dynamics Tools	Communication
D17-1	Video Conferencing	Shared File Repositories	Sharing Data
D17-2		Shared File Repositories	
D17-3		Shared File Repositories	Sharing Data
D17-4		Shared File Repositories	Sharing Data
D17-5		Shared File Repositories	Sharing Data
D17-6		Shared File Repositories	Sharing Data
D17-7		Shared File Repositories	Sharing Data

D17-8		Shared File Repositories	Sharing Data
D17-9		Shared File Repositories	Sharing Data
D17-10		Shared File Repositories	Social communication
D17-11	Messengers	Shared File Repositories	Social communication
D17-12		Shared File Repositories	Trust
D17-13		Shared File Repositories	Trust
D17-14		Social Tagging Systems	Shared Understanding
D17-15	Social Network Site	Social Tagging Systems	Feedback
D17-16	Team Management Groupware	Social Tagging Systems	Knowledge management
D17-17	Team Management Groupware	Social Tagging Systems	Knowledge Management
D17-18	Social Network Site	Syndication Tools	Communication
D17-19	Social Network Site	Syndication Tools	Communication
D17-20	Social Network Site	Syndication Tools	Communication
D17-21	Team Management Groupware	Syndication Tools	Communication
D17-22		Syndication Tools	Communication
D17-23	Social Network Site	Syndication Tools	Company Structure

D17-24	Team Management Groupware	Syndication Tools	Company Structure
D17-25	Messengers	Syndication Tools	Competency
D17-26	Messengers	Syndication Tools	Competency
D17-27	Team Management Groupware	Syndication Tools	Cooperation
D17-28	Messengers	Syndication Tools	Coordination
D17-29	Collaborative Document Editor	Syndication Tools	Feedback
D17-30	Messengers	Syndication Tools	Feedback
D17-31		Syndication Tools	Knowledge Management
D17-32	Messengers	Syndication Tools	Motivation
D17-33	Cloud Storage	Syndication Tools	Productivity
D17-34	Video Conferencing	Video Conferencing	Commonality
D17-35	Video Conferencing	Video Conferencing	Communication
D17-36	Video Conferencing	Video Conferencing	Commonality
D17-37	Video Conferencing	Video Conferencing	Communication
D17-38	Video Conferencing	Video Conferencing	Communication
D17-39	Video Conferencing	Video Conferencing	Communication
D17-40	Video Conferencing	Video Conferencing	Communication
D17-41	Video Conferencing	Video Conferencing	Communication
D17-42	Video Conferencing	Video Conferencing	Communication
D17-43	Video Conferencing	Video Conferencing	Communication
D17-44	Video Conferencing	Video Conferencing	Company Structure
D17-45	Video Conferencing	Video Conferencing	Competency
D17-46	Video Conferencing	Video Conferencing	Coordination

D17-47	Video Conferencing	Video Conferencing	Coordination
D17-48	Video Conferencing	Video Conferencing	Decision Making
D17-49	Video Conferencing	Video Conferencing	Decision Making
D17-50	Messengers	Video Conferencing	Feedback
D17-51	Video Conferencing	Video Conferencing	Innovative Thinking
D17-52	Video Conferencing	Video Conferencing	Innovative Thinking
D17-53		Video Conferencing	Innovative Thinking
D17-54	Video Conferencing	Video Conferencing	Knowledge capture
D17-55	Video Conferencing	Video Conferencing	Knowledge Capture
D17-56	Video Conferencing	Video Conferencing	Knowledge capture
D17-57	Video Conferencing	Video Conferencing	Knowledge management
D17-58	Video Conferencing	Video Conferencing	Productivity
D17-59		Video Conferencing	Shared understanding
D17-60	Video Conferencing	Video Conferencing	Shared Understanding
D17-61	Video Conferencing	Video Conferencing	Shared Understanding
D17-62		Video Conferencing	Shared Understanding
D17-63	Video Conferencing	Video Conferencing	Sharing Data
D17-64		Video Conferencing	Trust
D17-65	Cloud Storage		Access to information
D17-66	Social Network Site		Access to Information
D17-67	Video Conferencing		
D17-68	E-mail		Communication
D17-69	E-mail		Communication
D17-70	Social Network Site		Communication
D17-71	Video Conferencing		Communication

R15-1		Conversation Tools	Communication
R15-2		Conversation Tools	Communication
R15-3		Conversation Tools	Communication
R15-4		Conversation Tools	Communication
R15-5		Conversation Tools	Communication
R15-6		Conversation Tools	Communication
R15-7	Social Network Site	Conversation Tools	
R15-8		Conversation Tools	Company structure
R15-9		Conversation Tools	Company structure
R15-10		Conversation Tools	Competency
R15-11		Conversation Tools	Competency
R15-12		Conversation Tools	Competency
R15-13		Conversation Tools	Cooperation
R15-14		Conversation Tools	Cooperation
R15-15	Team Management Groupware	Conversation Tools	Coordination
R15-16	Video Conferencing	Conversation Tools	Coordination
R15-17		Conversation Tools	Coordination
R15-18		Conversation Tools	Coordination
R15-19		Conversation Tools	Coordination
R15-20	Messengers	Conversation Tools	Decision Making
R15-21	Social Network Site	Conversation Tools	Decision making
R16-1		Group Dynamics Tools	
R16-2		Group Dynamics Tools	Competency

R16-3		Group Dynamics Tools	Competency
R16-4		Group Dynamics Tools	Coordination
R16-5		Group Dynamics Tools	Coordination
R16-6	Messengers	Group Dynamics Tools	Decision making
R16-7	Messengers	Group Dynamics Tools	Decision making
R16-8	Video Conferencing	Video Conferencing	Decision making
R16-9	Messengers	Group Dynamics Tools	Innovative thinking
R16-10	Video Conferencing	Group Dynamics Tools	Innovative Thinking
R16-11		Group Dynamics Tools	Innovative Thinking
R16-12	Video Conferencing	Group Dynamics Tools	Productivity
R16-13		Group Dynamics Tools	Productivity
R16-14		Group Dynamics Tools	Shared Understanding
R16-15		Group Dynamics Tools	Shared Understanding
R16-16		Group Dynamics Tools	Shared Understanding
R16-17	Collaborative Document Editor	Group Dynamics Tools	Sharing Data

R16-18	Social Network Site	Group Dynamics Tools	Sharing Data
R16-19	Social Network Site	Group Dynamics Tools	Sharing Data
R16-20		Group Dynamics Tools	Sharing Data
R16-21		Group Dynamics Tools	Sharing Data
R16-22	Social Network Site	Group Dynamics Tools	Social communication
R16-23	Video Conferencing	Group Dynamics Tools	Social communication
R16-24		Group Dynamics Tools	Social communication
R16-25		Group Dynamics Tools	Trust
R16-26		Group Dynamics Tools	Trust
R16-27		Polling Tools	Commonality
R16-28	Messengers	Polling Tools	Communication
R16-29	Messengers	Polling Tools	Decision Making
R16-30	Social Network Site	Polling Tools	Decision making
R16-31	Social Network Site	Polling Tools	Decision making
R16-32	Social Network Site	Polling Tools	Decision Making
R16-33		Polling Tools	Decision making
R16-34		Polling Tools	Decision Making
R16-35	Social Network Site	Search Engines	Access to Information
R16-36	Social Network Site	Search Engines	Competency

R16-37	Collaborative Document Editor	Shared Editors	Productivity
R16-38	Collaborative Document Editor	Shared File Repositories	Access to information
R16-39	Cloud Storage	Shared File Repositories	Greater Productivity
R16-40	Social Network Site	Shared File Repositories	Access to Information
R16-41	Cloud Storage	Shared File Repositories	Artefact-mediated communication
R16-42		Shared File Repositories	Artefact-mediated communication
R16-43	Social Network Site	Shared File Repositories	Communication
R16-44	Social Network Site	Shared File Repositories	Communication
R16-45	Social Network Site	Shared File Repositories	Cooperation
R16-46	Cloud Storage	Shared File Repositories	Coordination
R16-47	Cloud Storage	Shared File Repositories	Coordination
R16-48	Cloud Storage	Shared File Repositories	Coordination
R16-49	Cloud Storage	Shared File Repositories	Managing the sharing of data
R16-50	Collaborative Document Editor	Shared File Repositories	Coordination

R16-51		Shared File Repositories	Coordination
R16-52		Shared File Repositories	Coordination
R16-53		Shared File Repositories	Decision making
R16-54			Decision Making
R16-55	Social Network Site	Group Dynamics Tools	Feedback
R16-56	Cloud Storage	Shared File Repositories	Knowledge capture
R16-57	Cloud Storage	Shared File Repositories	Knowledge capture
R16-58	Collaborative Document Editor	Shared File Repositories	Knowledge capture
R16-59	Team Management Groupware	Shared File Repositories	Knowledge capture
R16-60	Video Conferencing	Shared File Repositories	Knowledge capture
R16-61		Shared File Repositories	Knowledge capture
R16-62		Shared File Repositories	Greater Productivity
R16-63		Shared File Repositories	Knowledge Management
R16-64	Cloud Storage	Shared File Repositories	Knowledge management
R16-65	Cloud Storage	Shared File Repositories	Knowledge Management

R16-66	Cloud Storage	Shared File Repositories	Knowledge Management
R16-67	Cloud Storage	Shared File Repositories	Greater Productivity
R16-68	Cloud Storage	Shared File Repositories	Knowledge Management
R16-69	Cloud Storage	Shared Editors	Managing the sharing of data
R16-70	Messengers	Shared File Repositories	Knowledge management
R16-71	Team Management Groupware	Shared File Repositories	Knowledge management
R16-72	Team Management Groupware	Shared File Repositories	Knowledge Management
R16-73		Shared File Repositories	Knowledge Management
R16-74	Cloud Storage	Shared File Repositories	Productivity
R16-75	Cloud Storage	Shared File Repositories	Productivity
R16-76		Shared File Repositories	Productivity
R16-77		Shared File Repositories	Shared Understanding
R16-78		Shared File Repositories	Shared Understanding
R16-79	Cloud Storage	Shared File Repositories	Sharing Data

R16-80	Collaborative Document Editor	Shared File Repositories	Sharing Data
R16-81	Social Network Site	Shared File Repositories	Sharing Data
R16-82	Social Network Site	Shared File Repositories	Sharing Data
R16-83	Social Network Site	Shared File Repositories	Sharing Data
R16-84	Social Network Site	Shared File Repositories	Sharing Data
R17-1			Communication
R17-2	Social Network Site		Company Structure
R17-3			Company structure
R17-4			Company structure
R17-5			Company structure
R17-6			Company Structure
R17-7			Company structure
R17-8	Social Network Site		Competency
R17-9	Video Conferencing		Cooperation
R17-10			Cooperation
R17-11			Coordination
R17-12	Social Network Site		Coordination
R17-13	Social Network Site		Coordination
R17-14			Coordination
R17-15			Coordination
R17-16			Decision Making
R17-17			Innovative Thinking

R17-18	Cloud Storage		Knowledge management
R17-19	Messengers		Knowledge management
R17-20			Knowledge Management
R17-21			Knowledge management
R17-22			Motivation
R17-23			Motivation
R17-24	Social Network Site		Productivity
R17-25	Video Conferencing		Productivity
R17-26			Productivity
R17-27			Productivity
R17-28			Productivity
R17-29			Productivity
R17-30	Social Network Site		Shared understanding
R17-31	Social Network Site		Shared understanding
R17-32		Group Dynamics Tools	Shared Understanding
R17-33			Shared Understanding
R17-34	Social Network Site		Social communication
R17-35	Social Network Site		Social communication
R17-36	Social Network Site		Social communication
R17-37	Social Network Site	Conversation Tools	Social communication
R17-38			Social communication
R17-39			Social Communication
R17-40			Social communication
R17-41			Social communication
R17-42			Trust

R17-43			Trust
R17-44			Trust
R17-45			Trust
R17-46			Trust
R17-47			Trust
R17-48			Trust

Appendix 14: Dictionaries

Technology dictionary	
Cloud Storage	Box; Cloud; Doc*; Drive; Google; Share; Storage; Store.
Collaborative Document Editor	Doc*; Google; Live; Real; Share; Time.
E-mail	Email; E-mail.
Messenger	App*; Chat; Facebook; Instant; Memos; Messenger; Voice; Whats.
Social Network Site	Facebook; Group; Network; Page; Shared; Site; Social.
Team Management Groupware	Groupware; Management; Slack; Team; Tool; Trello.
Video Conferencing	Conf*; Google; Hangouts; Skype; Video; Webcam.

Technology functionality dictionary	
Audio Conferencing	Audio; Call; Memo; Phone; Voice.
Conversation Tools	Asynchronous; Chat; Comment; Communicat*; Convey; Decision; Discuss; Engaged; Familiar; Feedback; Informal; Information; Instant; Language; Making; Messages; Misunderstanding; Proactive; Rationale; Repetition; Reply; Response; Share; Sharing; Social; Speaking; Synchronous; Text; Translation; Understood; Update; Updating.
Desktop/Application Sharing	Animation; Augmented; CAD; Collaboratively; Draw; Ideas; Reality; Screen; Sharing; Technology; Whiteboard.
Group Dynamics Tools	3-6-5; Activities; Brainstorming; Breaker; CAD; Concept; Decision; Development; Exercise; Further; Ice; Ideas;

Technology functionality dictionary	
	Ideation; Iterate; Method; Research; Session; Sketch; Task; Turnaround; Visualisations.
Polling Tools	Activity; Consensus; Decision; Functionality; Mechanism; Pole; Vote; Voting.
Search Engines	File; Find; Search.
Shared Editors	Access; Concurrent; Live; Management; Overwritten; Real; Share; Simultaneous; Synchronous; Time.
Shared File Repositories	Access; Allocations; Assign; Available; Capture; Coordination; Data; Decision; Doc*; Held; Information; Manage; Manage; Note; Overwritten; Photos; Receive; Record; Repository; Retrieval; Scanners; Send; Sent; Share; Sharing; Sketch; Storage; Store; Storing; Track; Uploaded; Versioning.
Social Tagging Systems	Asynchronous; Aware; Channel; Feedback; Hashtag; Pinned; Rank; Starred; Tag.
Syndication Tools	Asynchronous; Aware; Connected; Fast; Hyperlinks; Inform*; Integration; Notification; Notified; Notify; Pervasive; Progress; Reminding; Speedy; Update.
Video Conferencing	Communication; Conf*; Conversation; Discussion; Face; Google; Hangouts; Resolve; Share; Skype; Synchronous; Understand; Video; Visual.

CSCD requirements dictionary	
A Shared Understanding	Aware; Clarif*; Context; Dissemination; Others; Rational; Summary; Understand; Understood.
Artefact-Mediated Communication	Communicat*; Concept; Drawing; Drew; File; Format; Idea; Image; Member; Over; Share; Support; Team;

CSCD requirements dictionary	
Building of Trust	Build; Built; Greater; Higher; Interpersonal; Issue; Lack; Levels; Relationship; Sense; Trust.
Communication	Based; Communicat*; Connection; Convey; Difficult; Discuss; Initial; Meetings; Messenger; Quick; Response; Summary; Team; Text.
Complexity Managing the Sharing of Data	Annotate; Avoid; Could; Data; Digitally; Document; Exchanged; Files; Finding; Idea; Image; Information; Knowledge; Live; Manag*; Outcome; Posted; Procedure; Research; Scan; Scanned; Share; Sharing; Showed; Sketch; Storage; Store; Storing; Uploaded; Various.
Cooperation	Activities; Activity; Activity; Agreement; Confus*; Design; Goal; Issue; Missed; Notifications; Personal; Split; Support; Task; Team.
Coordination	Allocations; Arrange; Arranging; Assign; Aware; Conduct; Coordinat*; Coordinat*; Could; Decide; Edit; Everyone; How; Interdependently; Manage; Multiple; Progress; Remind; Tasks; Teams; Version; Work; Working.
Decision Making	Apply; Consensus; Decision; Discuss; Knowledge; Mechanism; Organisation; Voting.
Development of Greater Competency	Accountable; Capable; Competent; Complete; Completing; Compliant; Considered; Most; Perceived; Reliable; Share; Struggled; Suitable; Tasks; Unreliable; Use.
Feedback Mechanisms from Stakeholders	Comment; Communicat*; Discuss; Evaluat*; Feedback; Other; Question; Sketch; Team.
Greater Productivity	Access; Around; Complexities; Conven*; Convenient; Easier; Effectiv*; Faster; Improve; Notify; Pervasive; Productiv*; Real; Reduced; Response; Simultaneous; Time; Turn.

CSCD requirements dictionary	
Innovative Thinking	3-6-5; Brainstorming; Concept; Highest; Innovative; Lowest; Method; Number; Session; Thinki*.
Integration with Company Structure	Across; Between; Change; Delegated; Formal; Gatekeepers; Leaders; Professional; Progress; Regularly; Relevant; Responsible; Scheduled; Team; Willing.
Knowledge Capture	Capture; Capturing; Difficult; Document; Record; Results; Share; Sketches; Take; Uploaded.
Knowledge Management	Cloud; Connected; Data; Decisions; Document; Found; Going; Held; Information; KM; Knowledge; Labelled; Location; Manage; Members; Missing; Requirements; Sections; Securely; Share; Store; Tag; Team; Tool; Well.
Motivation	Cohesion; Contribute; Demotivated; Motivated; Respond; Response.
Overcome Boundaries of Access	Access; Available; Constantly; Easy; Hosted; Inform*; Integration; Links; Manag*; Other; Programs; Share; Simple; Space; Understand; Uploaded.
Reduce the Barriers of Physical Proximity, Language and Time Zones (Commonality)	Barrier; Boundaries; Communicate; Complete; Confidence; Cultural; Culture; Difference; Different; Difficult; Disagreement; Geography; Issues; Knowledge; Lack; Language; Overcome; Plans; Same; Socialise; Summarise; Time; Work.
Social Communication	Activities; Activity; Breaker; Build; Communicat*; Discuss; Ice; Informal; Interpersonal; Meeting; Relationship; Social.