Comparing the Effectiveness of Face to Face and Computer Mediated Collaboration in Design

This Thesis is Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy (PhD)

By

Wadhah Amer Hatem

B.Sc. & M.Sc., Civil Engineering

Cardiff School of Engineering

Cardiff University

United Kingdom

August 2012

Supervisors: Prof. John Miles

Dr. Alan Kwan

ABSTRACT

Construction projects are complex and organisationally characterised by a high degree of fragmentation. This results in a need for clear communication and collaboration between the project participants in order to ensure the success of a project. Advances in communication technologies have enabled construction project members to supplement face to face (FTF) communication with methods based on computer mediated communication (CMC). The latter has reduced the need for travelling and hence results in savings in aspects, such as cost and time. One aspect of this CMC based communication is the emergence of modern design software which, together with other communication tools enables designers to undertake collaborative design while being geographically remote from one another.

The research in this thesis compares the effectiveness of FTF and CMC based collaboration for teams of two people at the design stage of a construction project. The comparison deals with many points that have been not addressed in previous studies and the analysis leads to the conclusion that CMC results in a more effective process than FTF in many aspects. For productivity, the results of this research reveal that team productivity for CMC is higher than for FTF and intriguingly further results show that the productivity score of two people collaborating is higher than for a single designer. Better time management has been found to occur with CMC than FTF.

This research found a method of measuring degree of collaboration between users in a team, as well as the results prove that the degree of collaboration in CMC better than FTF. In terms of design quality, the results show that the design quality for FTF is nearly equal to that for CMC. Other aspects of this research examine the relationship between non-verbal and verbal communication as well as between non-verbal communication and team productivity plus the impact of emotional factors on productivity and quality is also examined.

PHD THESIS RESEARCH ACHIEVEMENTS

- Hatem, W. A., Kwan, A. & Miles, J., 2012. Comparing the effectiveness of face to face and computer mediated collaboration. *Advanced Engineering Informatics*, Vol. 26, pp. 383-395.

- Hatem, W. A., Kwan, A. & Miles, J., 2012. Non-verbal communication during design. Paper submitted to *Design studies Journal*.

- Hatem, W. A., Kwan, A. & Miles, J., 2011. A comparison of face to face and computer mediated collaboration. In: Proceeding of International Workshop of European Group for Intelligent Computing in Engineering, EG-ICE 2011,Twente University, 4-7 July, Netherlands.

- Hatem, W. A., Kwan, A. & Miles, J., 2012. Factors affect team productivity in face to face and computer mediated collaboration. In: Proceeding of International Workshop of European Group for Intelligent Computing in Engineering, EG-ICE 2012, Herrsching, Munich 4-6 July, Germany.

ACKNOWLEDGEMENTS

First of all, I thank Allah for giving me the strength and the ability to complete this research.

I would like to express my thanks and gratitude to my supervisors, Professor John Miles and Dr. Alan Kwan for accepting me as a PhD student; they were always helpful, supportive and provided guidance throughout the research steps.

I am truly grateful to the Iraqi Ministry of Higher Education and to Cardiff University for their financial support which made it possible for me to carry out this research. I am also very grateful to the staff at the research office of the Cardiff School of Engineering, and in particular to Mrs Chris Lee, Julie Cleaver, Aderyn Reid, Hannah Cook and Jeanette Whyte for their continuous assistance.

Indeed, I have many people to thank, and I apologize in advance if I have forgotten anyone. I would like to thank all my friends and the volunteers who participated in my experimental work (Dr. Kayri, Asim, Sahand, Mandy, Ali, Alaa, Muhammad, Khalid, Mawie, Wisam and Najm) for their collaboration and support.

I would like to express my deepest and sincere appreciation to my Mother (Fatima) and my Father (Amer), to my brothers, Faris, Munaff, Muhammad and Ali as well as to my sisters Sroor, Najah and Zanab. They deserve considerable recognition and without their continuing support, patience, encouragement and true love this work would not be here today.

Finally, I am deeply grateful to my wife (Manal) for her constant love, kind help, moral support and encouragement throughout my graduate career which has imbued everything in my life with value. Lastly and not least, thanks go to my children, Amir, Monther, Dhiaa and Munthther for inspiring me in their own ways to complete my thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Acronym	Abbreviations
ICT	Information and communication technologies
CMC	Computer mediated communication
FTF	Face to face meeting
CSCW	Computer support collaboration work
VOIP	Voice over internet protocol
IT	Information technology
IFC	Industry foundation class
CAD	Computer aided design
VR	Virtual reality
DWF	Design web format (files)
P2P	Peer to peer
DNS	Domain name system
BIM	Building information model
NVC	Non-verbal communication
CCTV	Closed-circuit television
AEC	Architecture engineering and construction

Chapter 1

Introduction and Overview

1.1 Introduction

Construction projects are typically complex and present many different challenges. The first challenge is the project structure because the typical project in the construction industry is characterised by its high degree of fragmentation (e.g. multi-disciplinary stakeholders, many suppliers and contractors/sub-contractors) and each project consists of different sectors and each sector contains many activities and so on. Controlling all these sectors needs an excellent level of communication to manage these activities in the right way to get the best result in terms of project productivity, reduction cost and time, etc. The second challenge, which affects the performance management in construction industry, is that these projects and participants are located in different geographical areas and therefore the communication between the project participants and their administration will be difficult. Therefore, effective and appropriate communication is necessary between administration and projects parties to avoid any problem which occurs in each construction stage.

Since the word "communication" is commonly used for different purposes, the current work follows the definition in the human factors in computing system and management literature (Gergle, 2004; Sannie, 2006) which define communication as a process that includes the transfer of information, ideas, knowledge via different methods such as words, pictures and signs. Similarly, "collaboration" is defined as generation and sharing of information between individuals toward a particular purpose (Kwan & Ofori, 2001; Pena-Mora et al., 2001; Amabile et al., 2001). Communication and collaboration in the construction industry have witnessed a great development in the recent years particularly as a result of using the internet and the emergence of modern software and especially design software. Internet and wireless based communication has become a competitor for the traditional method of communication, which is referred to in this thesis as "Face to Face" (FTF). Due to a vast improvement in advanced communication technologies, "Computer Mediated Communication" (CMC) has become a viable method of collaborative working, because it permits people to communicate at any time and location (Rosen et al., 2007). CMC offers the advantage of being more economical than FTF because the latter requires expenses such as travelling and accommodation, which can be avoided by using CMC (Abdul-Gader, 1996).

Some of the most important benefits to the construction industry from the use of the modern technology are the ease with which information can be stored, transmitted and shared. For example, the development of Building Information Modelling (BIM) has facilitated better design collaboration, interoperability, clash detection and planning (Dzambazova at el., 2010). The result is a speeding up of the process of construction, an improvement in the quality of schemes and enhanced management processes. Another recent development is the appearance of software tools which can support collaboration and communication by geographically remote participants, allowing for example shared access and collaborative working regardless of time or location. These developments are potentially of a great significance to the construction industry with its highly fragmented structure which leads to many separate and geographically remote organisations being involved in each scheme.

This research studies the how collaboration works during the design process for mature design and compares the differences between two methods of achieving collaboration, namely: FTF and CMC. The task used in this research is solving problems in an existing design task and the model is simple and represents a house. The experiments were conducted by many participants who came from different cultures and have different expertise levels. The collaboration software used in this research is Autodesk Revit Architecture which has, amongst other features, facilities to help people who are geographically distributed in different places to work remotely and to solve design problems.

1.2 Aim and Objectives of Study

The aim of this research is: to assess the differences that occur when people undertake engineering design tasks in FTF (including a particular study on some of non-verbal communication components) and when working remotely from one another using a network in CMC. This aim is realized through achieving the following five objectives.

1-Communication quantity, time consumed and behaviour profiles: There are three points considered in this objective as follows:-

1. To identify the communication quantity for team in each method (i.e. FTF and CMC), i.e., the total number of words, work related words, etc.
2. To clarify the time consumed in undertaking the task for each method and each team.
3. To study the behaviour profiles for each user for the two communication methods and to determine which method is most conducive in terms of supporting communication.

2-Productivity: There are three points of study in this objective as follows: **-**

1. To identify which method gives higher productivity.
2. To determine which factors affect team productivity.
3. To compare between team productivity and single user productivity for the same engineering design task.

3-Degree of Collaboration (level of interaction or amount of participation between users in the team): There are two aspects to consider in this objective as follows:**-**

1. To determine the best indicator for degree of collaboration between team users.
2. To determine which factors influence the degree of collaboration.

4-Design Quality: There are three points to be studied in this objective as follows:**-**

1. To identify which method gives the best design quality.
2. To study the effect of factors such as expertise level and emotional profile on design quality.
3. To compare between the design quality achieved by a team and single user.

5-Non-verbal communication in FTF: There are two points in this objective as follows:**-**

1. To categorise the main non-verbal communication components observed in the FTF experiments.
2. To examine the impact of each type of these components on team productivity.

1.3 Scope and Limitation of Current Research

In all previous studies and particularly those of collaboration and communication in the design phase for the construction industry, the research does not consider many points which are important in team productivity and collaboration. This research covers many of these previously omitted aspects as follows:-

Objective	Scope
1	Communication quantity: this being a detailed analysis of the number of words in both FTF and CMC, with a percentage breakdown of whether these are work-related words or not, and the relationship of these to productivity. Additionally, a further analysis on the tone of voice (i.e. emphatic or soft) over the duration of the experiment is also carried out, which is further examined in the context of participants' behaviour.
1	Time types (productive and non-productive) and which method is better in time management plus additional, studies of the relationship between each time type and team productivity.
1	The effect of behaviour profile, which is divided into three categories, positive, neutral and negative emotions, on team productivity, collaboration and design quality.
2	Team productivity in each method (i.e. FTF and CMC), and the effect factors such as expertise level, cultural differences and prior relationships for team users on team productivity.
3	Finding the best indicator for the degree of collaboration between the users in the team.
4	Comparisons of design quality between results produced using FTF and CMC.
5	The effect of some of non-verbal communication components (body movements (including facial expression), eye contact and changing voice) on team productivity in FTF.

In this research, there are some limitations which need to be noted from the outset.

- The time (three years) available for the research meant there was a limited number of experiments that could be conducted and then analysed, more experiments would have allowed the conclusions to be more generalised.
- Since the experiments were conducted by volunteers, there was a difficulty to increase the numbers of users for extra experiments, so the research was conducted on a limited sample size of users.
- Some of the evaluation of the results was necessarily subjective in nature (e.g. evaluation of productivity, behaviour profile and design quality) and potential evaluation bias would have been minimised by employing a pool of expert evaluators. This was not possible within the constraints of resource, and hence there is potential evaluation bias in the results presented.
- The volunteers for the experiments were later categorised according to expertise level, and ideally, an even distribution of expertise was required. It was difficult to find volunteers of specific required expertise level at any given time.

1.4 Outline of the Thesis

A summary of the contents of the subsequent chapters is as follows: -

1. Chapter Two gives details about the literature review for this research and the important past studies in this area.
2. Chapter Three considers the research methodology used in this research and explains the experiments' requirements, how they were conducted and how the results have been classified and analysed. Finally, this chapter gives information about the collaboration software (Revit Architecture) which is used in this research and explains the hardware and operating software used.
3. Chapter Four (Objective 1), provides a general comparison between FTF and CMC; this comparison includes the total words said by each team and each user broken down into two categories: work related words and non-work related words. Also this chapter discusses the time division between working, wasted and non-specific time. Finally, it considers the number of exchanges in speech, team

productivity by each team and the behaviour profile for each user in each method, and compares between speech rate for each user in FTF and CMC.

4. Chapter Five (Objective 2) studies team productivity for FTF and CMC and considers the factors which affect productivity. This chapter also compares team productivity with that of a single user.
5. Chapter Six (Objective 3) considers collaboration and determines suitable indicators which reflect the degree of collaboration.
6. Chapter Seven (Objective 4) examines design quality for FTF and CMC, factors which affect design quality and the relationships between design quality and team productivity and degree of collaboration, and finally compares between single user and team design quality.
7. Chapter Eight (Objective 5) studies some of non-verbal communication components in FTF; this includes an analysis of the results according to expertise level.
8. Chapter Nine draws conclusions according to the results obtained and makes recommendations for future studies.

Chapter 2

Literature Review

2.1 Introduction

This chapter provides an overview of literature pertinent to the subjects covered in this thesis, and is divided into the following nine main sections.

1. Section 2.2 studies communication in construction industry which includes definition, importance and actual need for modern communication.
2. Section 2.3 considers collaboration in construction industry which includes definition and importance, benefits, collaboration software and system architecture in collaboration work.
3. Section 2.4 covers FTF and CMC characteristics and compares face-to-face (FTF) and computer-mediated-communication (CMC) in general which includes different aspects such as task time, social relationships, trust building, etc., with the advantages and disadvantages of each method also explored.
4. Section 2.5 compares FTF and CMC in the construction industry which includes the previous studies which are concerned in aspect of FTF and CMC in construction.
5. Section 2.6 studies the “team” which includes definition, importance, type and size as well as teams in the construction industry.
6. Sections 2.7 and 2.8 examine team productivity and the factors affecting team productivity.
7. Section 2.9 discusses collaboration and how it can be measured which includes degree of collaboration importance, and previous work in this degree.
8. Section 2.10 explains team design quality and the factors affecting it and furthermore, comparisons between the quality of work carried out in FTF and CMC.
9. Section 2.11 studies non-verbal communication definition and importance, aspects relating to non-verbal communication components and analysis of these components.

The three main bodies of the literature in which the current research is seated is in: Communication, Collaboration and Information technology which accounts for around 40% of the cited references (including 9% for non-verbal communication); Management (including Construction Management) which represents 25% of the cited works; and Social Psychology (accounting for about 20% of the references). The remaining 15% of the quoted literature come from more diverse areas, including design, organization, and education.

2.2 Communication in Construction Industry

This section explains communication, its definition, and the importance of communication in construction and construction's needs for modern communication.

2.2.1 Communication Definition

Communication processes can be defined as the transfer of information from one entity to another. In its most basic form, communication can be divided in two main categories, verbal and non-verbal (Gergle et al., 2004). Verbal communication involves spoken conversations between people while non-verbal communication uses body language. The content of verbal communication is largely overt and hence easily comprehended. Non-verbal communication is largely subconscious and less easily understood therefore the participants in FTF communication tend not to be consciously aware of the non-verbal messages which are being sent to each other but nevertheless, they respond to these signals which can be very powerful. In FTF conversation, typically at least 50% of communication is non-verbal (Goffman, 1959).

Communication traditionally occurs between two or more people who are FTF but can also include the exchange of information in other modes such as the exchange of paper based documents (Keyton, 2011). More recently communication has come to include the process of exporting and importing data in various formats (i.e. text, 3D models, tables and ideas) and since the development of high speed networks, this has been extended to include VOIP, chat, shared desktops and visual communication via webcams. Network-based communication is grouped together under the collective name Computer Mediated Communication (CMC) (Herring, 2003; Miller, 2009).

2.2.2 Importance of Communication in Construction

The organisation of the construction industry is characterised by its high degree of fragmentation with there being many small companies (Dainty et al., 2006). Construction project management generally tries to make the communication clear and consistent during all phases of the project, in order to get guidance to all members of the project according to the organizational structure of the company. Communication in the construction industry is one of the most important factors for the success of a project (Akintola et al., 2000), therefore construction project management needs effective and vital coordination and collaboration between the different project members to discuss and find the best solution for the problems which occur during any stage in the project. The administration can achieve this goal by choosing appropriate communication flows between all participants.

Despite the importance of communication in construction, it still faces many difficulties and problems, due to the types of organization and the availability of the resources used as well as the type of relationships among project participants. Adoption of suitable information and communication technologies (ICT) helps to overcome the obstacles facing the implementation of collaboration between the team members (Egbu et al., 2001).

2.2.3 Construction Needs Modern Communication

One of the significant challenges faced by some of the stakeholders in a typical construction project, who are geographically remote from one another, is the requirement for their physical presence at the construction site or at design meetings to understand the construction work activities effectively. It is not always easy for all the stakeholders to be collected or to come together on a short term basis.

This problem can potentially be avoided by modern communication methods using certain types of media which will enable the stakeholders to communicate with each other effectively and discuss design challenges or monitor the work process continuously from a distant place without the need for being at the construction site (Sze-wing et al., 2008). Research suggests that the collaboration between different specialists using web-based solutions, allows designers and other users at the design stage to build an integrated model using both in-house and distributed resources, at the same time it makes collaboration easier by exchanging the service information in a network centric environment (Peltoniemi & Jokinen, 2004).

The development of modern multi-media technologies, particularly the internet, has made a significant impact on the construction industry. It is hypothesized that these technologies have resulted in an increase in productivity for each stage of the work (Wong, 2007). Using CMC (i.e. remote communication) enables the disciplines to communicate, share their information and increase team productivity with minimal social effects. Hatem et al. (2011) studied two modes of collaboration in FTF and CMC, the work involves 20 experiments each of which involves two participants undertaking a simple design task. They found that, in CMC, team productivity was higher, behaviour profile was better, speech and time distribution between users was more even, domineering behaviour was less evident, and the number of exchanges (collaboration degree) between users was higher. The limitations of these finding are covered in this thesis (see Section 1.3).

2.3 Collaboration in Construction Industry

This section provides a general view about collaboration, its definition and importance, the benefits of collaboration in construction industry, the role of new technology and software in supporting collaborative working and finally the sort of systems architecture needed to support collaborative working.

2.3.1 Collaboration Definition and Importance

In spite of collaborative working being widely discussed in the literature, there is no accurate, comprehensive definition. Linguistically, it can be defined as working jointly (Oxford Dictionary, 2001), this indicates that in this form of work all participants work together to complete their mission. Technically, collaboration defines the agreement among stakeholders to share their skills and information in specified items to achieve the best results in aspects of quantity and quality (Kwan & Ofori, 2001). Collaboration involves the generation and sharing of information events and actions, moreover effective communication is necessary to obtain meaningful collaboration (Pena-Mora et al., 2000).

Collaboration in the construction industry is one of the important aspects which can't be ignored if administrations want to achieve their goals in any project and it is a critical success factor for company survival and performance by responding to the environmental variables to resolve fragmented problems in the construction field (Hartmann et al., 2009). The construction industry is characterized high fragmentation and this might have a negative effect on team performance and productivity without good collaboration between team members. Good collaboration and, where appropriate using new technology, particularly information and communication technology (ICT) helps the team to achieve their goals and leads to change in the construction industry environment (Xiaolong et al., 2007).

2.3.2 Collaboration Benefits in Construction Industry

Collaborative working is essential in a highly fragmented and multi-disciplinary industry such as the construction industry and the development of information technologies and associated communication infrastructures, has impacted on the business processes that have followed traditional paths for a long time (Van & Fridqvist, 2006). Continuous and effective collaboration between project participants is a key factor in resolving conflicts and keeping projects to budget and on time (Howell, 1996). Another important aspect of working in any industry is that junior members of staff need access to and guidance from those with expertise. Previous research suggests that CMC can assist with this in cases where the expertise is geographically remote (Jeffrey et al., 2007), and it also allows for people to communicate easily and directly with one another across space and time (Nohria & Eccles, 1998).

2.3.3 Role of New Technology and Software in Collaboration Work

Developments in computational technology and software have assisted in the development of new methods of collaboration, for example networking software and hardware have witnessed a significant evolution during recent decades (Halfway & Froese, 2004). This has enabled geographically remote users to interact and collaborate without the need for travelling to FTF meetings. Most sizable construction companies are moving towards the use of innovative working such as meetings using network communication. These companies have adopted group collaboration to achieve their goals, using modern technologies to connect these groups, which are distributed in various locations, as if they are sitting in one room and at one table (Lee, 2011). Collaboration in the construction industry has developed considerably in recent years by the adoption of the modern methods and techniques of advanced communication. Computer-Support Cooperative Work (CSCW) or Computer-Mediated Communication (CMC) technologies represent a revolution in the world of the work; they are supported by communications which has added considerably to the development of architecture, engineering and construction (AEC) (Xiaolong et al., 2011).

Design software such as Revit Architecture, Bentley MicroStation powerdraft V8i, AutoCAD Architecture, Allplan Architecture, etc, like other IT technologies has witnessed a significant evolution during recent years. Design tools in the construction industry software have been developed from 2D drafting to 3D modelling, these innovations don't only change the way building designs are visualized, but represent a significant changes in designers' thinking from pure visualisation to simulation (Robyn, 2005).

These developments, together with developments in communication technology have facilitated a new form of collaborative working which can be used by individuals or teams who are remote from one another. These tools such as collaboration tools which were not available previously allow all project team members to coordinate with each others, enhance design accuracy, reduce time and cost and make corrections (Wing, 2009). For hardware and the internet it has been found that high speed internet access to remote construction sites and the appearance the new methods of communication such as video conferencing, IP camera, etc can support communication in construction industry (Alaghbandrad et al., 2011).

2.3.4 System Architecture in Collaboration Work

There are several types of system architecture which can be used to support collaborative working, but commonly, there are two main types of these systems.

2.3.4.1 System Net. Peer to Peer (P2P)

Sometimes called replicated model, in this system a peer finds and identifies another peer by using a special window called a Domain Name System (DNS). This system is characterized by not having a server in its structure; instead each computer has a copy of shared data. This style of system has become common and a lot of people use it, because it has a high transmission capacity between partners and because of its ability to retrieve and save this information in an effective way (Yang and Garcia-Molina, 2002). This style of system however also has disadvantages such as lack of security and reliability in addition to which it lacks a centralized control, Fig. 2.1 shows the peer-to-peer networking system. Many researchers have adopted this system such as Chen and Tien (2007) and Zurita et al., (2008).

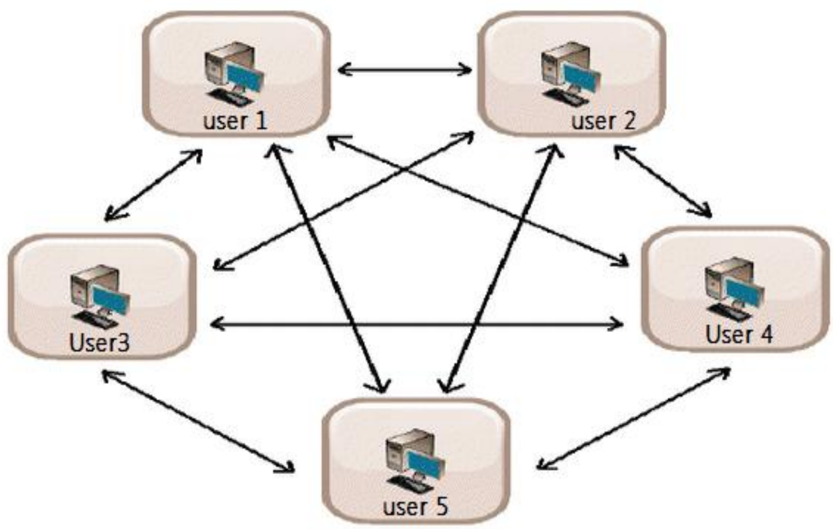


Figure 2.1: System Net. Peer to Peer (P2P) (Yang and Garcia-Molina, 2002)

2.3.4.2 Central Model or Client/Server

This system has a fixed server in one place such a project centre or headquarters office which is connected with many computers in different places (cloud computing). Any shared file is saved in the central server and any user can access this server if they have the requisite permission from the administrator who is responsible for operating and managing the system. This system has many advantages when compared with other systems, so that it can be relied on during the collaboration work for example, it centralizes resources, it has flexibility and it is more easily made secure. At the same time it has some disadvantages, for example, it is costly, the system slows down when the number of users exceeds certain limits and if the server is disrupted the entire network fails (Amiri, 2002), Fig. 2.2 shows the Client/Server system.

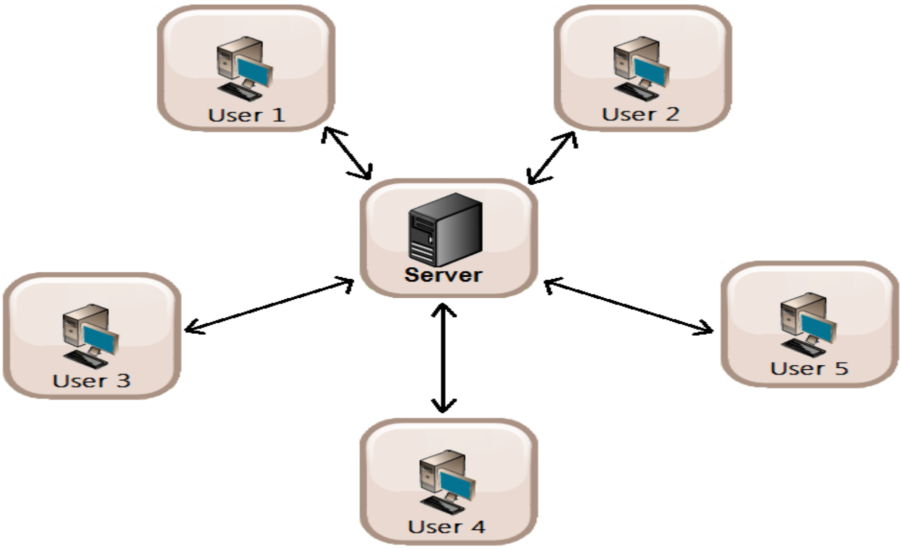


Figure 2.2: The central Model or Client /Server (Amiri, 2002)

2.4 Comparison between FTF and CMC Communication

Many researchers have made comparisons between FTF and CMC to show the merits and characteristics of each method. This section therefore examines these general comparisons, looking at FTF and CMC characteristics and the differences between them.

2.4.1 FTF Characteristics

A considerable amount of study has been carried out on the advantages and drawbacks of FTF collaboration and communication. An and Frick (2006) asserted that FTF better than CMC in many aspects, their study concerned the university residential allocation of 105 students in time-limited FTF and CMC discussions and form filling. They reported that 65.7% of the total students confirmed that FTF communication is faster, easier and more convenient than CMC in an educational context. They additionally claimed that 74.3% were of the opinion that FTF communication is better when communicating ambiguous tasks and finishing complex ones. Kaushik et al. (2000) stated that FTF communication represents a high social presence in high collaborative task (i.e. the quality of the medium of communication). The number of "idea unit" was found to be 11% higher in FTF than in CMC where "idea unit" (as defined by Chafe, 1980) comprises the number of words, number scenes and number of characters, and is a parameter to determine cognitive chunking of words by speaker. The study by Kaushik et al. (2000) comprised teams of 8-12 students (108 in all) who were required to complete a fictional story in 30 minutes, with half the groups working in FTF and the other half in CMC.

Barkhi et al. (1999) claimed that FTF communication is an efficient process for intra-organisations communication, resulting in a superior overall performance. They also asserted that the uses of verbal communication could be improved by facial cues. Their study includes four teams, each with six members, who discussed production planning problems for a manufacturing company. These discussions were not limited by time, and the teams worked in both FTF and CMC (in random order). Their claims resulted from noting that 94.76% of the FTF teams achieved their task by supplying the customer orders, while only 66.89% of CMC teams managed this. Communication routes using traditional media, such as FTF interaction still play a significant role in workplace communication, even though CMC is pervasively used in the workplace (Lee, 2010). This result emerged from a study of 15 people in five organisations who were asked about the communication effectiveness of FTF and CMC, and 60% of the survey people expressed that FTF was superior to CMC, while 20% considered CMC was better, and the remaining 20% recommended a combination of both FTF and CMC. For this study the researcher used questionnaires, but the items of these questionnaires were not known in the study and this weakens the certainty of the findings.

Van der Meijden & Veenman (2005) examined the effects of collaboration for FTF groups, comparing them with CMC groups. These concerned the interactive behaviour and task performance of 42 pairs of pupils (in a Dutch primary school). Here, their study concerned students working in a collaborative way on a mathematics task. Their results illustrated that the FTF pairs presented significantly higher-ranking elaborations (70% of utterances) than the CMC pairs (53% of utterances) when resolving the mathematics problems.

2.4.2 CMC Characteristics

The term CMC is widely used in different fields, such as organizational communication (Rice, 1986), educational computer conferencing (Harasim, 1986), social communication (Riva & Galimberti, 1997), and so forth. CMC has thus become increasingly common in the past two decades because of the fast developments in computer software and communication systems, and particularly with the internet (Thurlow et al., 2004; Dietz-Uhler & Bishop-Clark, 2001). These developments have been used in almost all industries, including construction. CMC technologies comprise computer conferencing, e-mail, databases, online chat and Web-based environments. These technologies are widely used for different purposes such as strategic planning, evaluation, product assessment and project collaboration and coordination (Adams & Galanes, 2009).

Warkentin et al. (1997) described a set of procedures designed to improve and develop the interaction experience of a virtual team at work. Their study used undergraduate students in various American Universities to discuss social problems with the aim of finding solutions. There were 13 and 11 groups for FTF and CMC respectively, and each group consisted of two people. The results showed that the CMC groups achieved their solution faster than the FTF groups, and the performance of each group in FTF and CMC also depended on whether the group members previously knew each other. Takao (1999) studied the difference between FTF meetings and two modes of videoconferencing: a video of just the speaker and a video of all the participants. The task involved the NASA moon survival programme and had 200 participants, all of whom were students, and their answers were evaluated for correctness by compared to the correct answer provided by a panel of NASA expertise. The results showed that the decision making was at its most effective when all the participants appeared on the video.

Lantz (2001) studied the impact of a CMC session designed to support collaboration between experienced individuals who are geographically remote from one another. He discussed the differences between FTF, chatting and CMC meetings in terms of their efficiency. The participants were composed of six small groups, each group having four experts in information technology who were monitored during their usual work meetings (with a typical duration of around one hour). The method of data used here was that of questionnaires. The results obtained revealed that chatting and CMC-based meetings were more knowledge-rich and task-oriented than FTF meetings.

2.4.3 The Differences between FTF and CMC

This section considers the differences between FTF and CMC according to a variety of terms including the task time, the effect of a social presence and visual feedback, trust building , the task type as well as the decision making and satisfaction as follows:-

2.4.3.1Task Time

Task time is one of the most important parameters with which to evaluate team performance when completing a task. From the results of 18 experiments studies carried out in different fields, such as business, psychology and sociology in terms of collaboration effects of working in both FTF and CMC groups, Bordia (1997) concluded that: (a) the CMC groups took a longer period of time than FTF groups to complete the allocated task (although this difference may have only be due to typing which requires more time than speaking); (b) the CMC groups generated fewer remarks within a specified time period than the FTF groups; and (c) when time was restricted, the CMC groups performed 21% better in the tasks than the FTF groups; exception to this were the tasks requiring greater social-emotional interaction. However, the observed differences between the groups disappeared when there was an adequate amount of time.

Regarding to task time also, Hancock and Dunham (2001) found in their experiments involving pairs of users, that those communicating in FTF completed their task in 20.73 minutes, while CMC pairs required 36.22 minutes to finish the same task. The task was to carry out a psychological observation of other participants by completing a form with 60 items on five factors of personality. This was concluded from a study of 84 English-speaking (12 male and 72 female) members of the university community, who were randomly paired into 42 pairs, with half the pairs in FTF and the other half in CMC. No time limit was imposed on the tasks, and all the participants knew each other beforehand.

2.4.3.2 The Effect of Social Presence and Visual Feedback

Some authors have argued that performance defined according to parameters, such as productivity, collaboration, quality, etc., in CMC groups is higher than the performance of

FTF groups because of the lack of a social presence in the CMC groups. Thus, a less individual and socio-emotional form of interaction and a more task-oriented form of collaboration occurs when using CMC. The absence of social interaction and non-verbal cues for collaboration and communication may even create an important level of anonymity. In this way, there is a higher incidence of rude or offensive behaviour in CMC in contrast to FTF (Straus, 1996). The latter study was carried out on 54 people who were divided into groups; each group consisted of three people who discussed a problem solving task in information technology, either using FTF or CMC. Here, the absence of visual feedback affected team performance in terms of the decision making.

Similarly, Sniezek and Crede (2002) described decision making in a CMC environment as having a number of deficiencies because of the lack of visual feedback, and the ‘inhumanness’ of technologies. Their conclusion came from observing that FTF teams had higher confidence in their team judgments than did CMC teams. The physical separation for team members in CMC also reduced the interaction, which the authors saw as a cause for a higher degree of incorrect decisions being made. Additionally, FTF interaction was found to endorse a greater degree of team ownership of the final solution. This study involved 189 students working on different estimation tasks without a time limit, some students worked individually, while the rest were in teams of three and were using either CMC or FTF. Additionally, the students not previously acquainted and randomly placed into teams.

2.4.3.3 Trust Building

In the process of building trust between participants through communication, Wilson et al. (2006) found that the trust between the participants during the activity of communication began at a lower level in CMC teams who were working collaboratively, in comparison to teams operating in FTF. Finally, however, the trust levels became similar; suggesting that time is a factor in building trust in CMC. This was concluded from a study of 156 students in teams of three who were working on a 1-hour financial task, in both FTF and CMC (with random order). It was noted that a prior knowledge of other the participants helped to build a strong degree of trust in both FTF and CMC (Rocco, 1998).

Bos et al. (2002) found video and audio chatting to be as efficient as FTF meetings in terms of the building of trust between different team members. This contrasted with text chatting, which was below expectations. However, all types of communication other than FTF communication were associated with what has been named “delayed trust” or “fragile trust” between members of a team. The study was carried out by sixty-six people who were divided into groups, each group consisting of 3 people. The task was a social one since the students “played a social dilemma game called Daytrader” and the task time was not limited.

2.4.3.4 Task Type

The task type has a big effect on team performance in the two methods. Hollingshead et al.(1993) divided the tasks into four types (a) the generating task (b) the decision-making task (c) the negotiation task (d) the intellective tasks (these being tasks designed for group work, for which there is a known correct solution). They found CMC to be superior to FTF in the “brainstorming”' (generative task) and decision making tasks, but FTF was better for tasks such as negotiation and intellective tasks. Straus and McGrath (1994) discovered that the overall effectiveness of the FTF groups was lower than that of CMC groups, particularly for tasks that required higher levels of collaboration and decision making. Their study involved 72 students working on three separate social problem tasks (an idea generation task, an intellective task and a judgement task). However, the CMC groups achieved better results than the FTF groups as regards idea-generation tasks (Bordia, 1997).

2.4.3.5 Decision Making and Satisfaction

In decision making and from the point of view of satisfaction, studies have shown a variety of findings in these areas. Generally, authors have supported CMC to a certain extent; they have indicated that CMC gives team members a structured environment which enables them to collaborate effectively and to interact simultaneously in order to create ideas and make better decisions than the team members in FTF (Jessup et al., 1990). The latter study was applied in a social psychological area to establish the decision making in group decisions according different methods of communication. The CMC team members here were more confident and satisfied than the FTF members in making successful decisions because this approach is characterized by high flexibility and a rapid response capability and, additionally, encouraged greater reflection (Cohen & Scardamalia, 1998). The study contrasted two groups at work in FTF and CMC, each group consisting of 6 students who undertook a psychological problem task; the duration was for each task was 12 weeks.

In contrast, other researchers have found that FTF team members have a good environment in which to take decisions, resulting in better quality than CMC. In one study, the lack of non-verbal communication and social presence made team members in CMC feel uncomfortable and disinterested in other members which led to a decrease in the satisfaction and intimacy between the team members (Valacich & Sarker, 2002). This study was carried out by 274 students in the Business School of an American university. The students were divided into groups, each consisting of three people, and the task was a financial and accounting one.

In all the previous studies, different (but comparative and similar) tasks were used in FTF and CMC, and the order was random. Some of these tasks had time restrictions (e.g. 20, 30 or 60 minutes), while others were allowed to run until completion. The literature reviewed covers a wide range of tasks, such as accounting, reading, planning, estimating, and mathematical.

2.5 Comparison between FTF and CMC in Construction

This section concentrates on the comparison between FTF and CMC in the construction field and explains important studies relating to this aspect.

Substantial research has investigated the use of computers in the communication and collaboration process for the construction sector; and it contrasts with traditional methods. Some of this research has studied the mechanism of the communication, such as the use of audio equipment, video or both. Other research has focused on the quality of these mechanisms, comparing them to the traditional methods of FTF meetings. Dawood et al. (2002) developed a methodology that facilitates graphical communication (construction drawings) in CMC and the mixing of data/ information between construction project team members. This system was tested by making a comparison with a paper-based system in a construction project in the UK. Their results showed a saving of more than 90% in man-hours and £9000 from the drawing printing cost (i.e. a large saving in costs for the CMC based approach). Their findings resulted from interviews with the site engineer and three of design team members (the architecture, structural and mechanical working in the real project). Deng et al. (2001) improved an internet-based system that assisted and facilitated engineers in controlling and following the progress of a construction industry project on a small-scale real-life project (residential housing) in China. The results were obtained by comparing the time and cost for the completed items in the project with the estimated cost and time for these items. The results showed that CMC communication improved the degree of control of the costs of the project; it provided an excellent opportunity to monitor the project progress every day and enhanced the management and decision making, so improving the performance of the construction companies. This system had previously been tested with a group of participants recruited from local construction industry companies in Hong Kong (Tam, 1999). The earlier test had verified the reliability of the system and demonstrated a saving cost to the companies of around 5% (total project cost) compared to companies working without this system.

Faraj et al. (2000) develop an IFC-based collaborative computer environment that enables communication through a networked system. This environment supports design (CAD) visualization (VR & DWF), estimation, planning and supplier information, and their conclusion was this environment gives greater flexibility to all construction participants to achieve, monitor and manage their activities wherever they are and at any time. This system had previously been tested and compared with FTF (Fruchter, 1998), with a group of students at Salford University, and the results show design time was reduced in CMC and rate of production of individual results was higher, but there are not specific percentages given for them (i.e. design time and individual productivity). In this study no information about task time and group number was given and this makes its more difficult to compare with other studies. Hewage et al. (2008) also examined the use of modern communication technology, e.g. through personal digital assistants and hand-held devices on a construction site. They also examined the access opportunities for the use of these devices. The study participants were divided into three separate groups (construction managers, construction workers and technology providers), each group consisting of 15 people. The information was collected using questionnaires, interviews and through observation; the results showed that the use of modern communication devices (CMC) among skilled workers increases the daily productivity and reduces the time wasted on the project.

Rezgui (2007) pointed out that the possibility of using CMC successfully in the construction industry does not solely depend on the adoption and use of effective information communication technology (ICT) but also rests on an integrated analysis of social and organizational concepts, such as team identification, trust, and motivation. Here, the research was applied to two small and medium-sized projects in France and Finland. It addressed three factors: technology adoption, organizational structure and social relationships. Other authors have also previously studied the relation between social factors and team efficiency such as (Bannon, 1999; Kart & Kart, 2003).

Pena-Mora et al. (2009) examined the effect of team interaction spaces in FTF and CMC on the total performance using quantitative and qualitative data. They collected their data by conducting interviews with 500 members who were distributed in different places in 3 companies. The researchers concluded that the advanced technology used by the dispersed team required skills and reliability in the use of the interaction technology. In addition to their ability to use and access this technology from various places, they also established that there was a close link between the support for the use of this technology and team efficacy.

Hegazy et al. (2001) created an information model to expedite design collaboration and the management of design change. The main benefits for this model were that it increased design coordination and control of changes. In addition to this, the model increased the productivity of the design process. The proposed model was built around a central library of general building components which could be used to illustrate the hierarchy of a whole building project. Each component permits the designer to store the required performance criteria and the linking design rationale. Each one is also sensitive to its own modifications and automatically communicates such changes to the affected parties by means of preset communication methods. This system has been tested by Zaneldin et al. (2001); the test was an invitation for 90 academic researchers and industry professionals to view live presentation of the system's use in a case study which was a simple hypothetical two-floor concrete building and the participants were working in this case study (principally engineers specialising in structure, architecture, mechanical and electrical).

The opinion of the attendants was then obtained by a questionnaire of 26 questions, and the results of the analysis of these questionnaires revealed that 70% of the respondents perceived that proposed system implies notable changes to traditional work habits.

In all previous studies, and particularly in those conducted in the construction industry, researchers have failed to address several factors which are important in team productivity and collaboration. In particular, in the construction industry, and especially in the design stage, the literature on collaboration does not show any metrics with which to assess the working of the collaborative process. The work on metrics of collaboration has come from authors in other fields, such as the supply chain relationship and in the field of education. This research therefore seeks to address these deficiencies, as will become apparent in the following chapters. Furthermore, while many studies have considered the effect of emotional factors on product development, such as Akgün et al. (2009), or the relationship between the team members' conflict and team emotions as investigated by Barrick et al., (1998), the current research concentrates on the impact of three types of emotional factors (positive, neutral and negative) on team productivity, design quality and collaboration in both FTF and CMC. Uniquely, this research studies the relationship between some components of non-verbal communication (NVC) which are principally body movements (including facial expression), eye contact and voice tone with team productivity in FTF.

2.6 The Team

In this section team characteristics in general are examined, including: the team's definition, importance, the formatting of the team according to size and time as well as looking at teams in the construction industry.

2.6.1 Team Definition

It is difficult to find a specific definition for the word team because its definition mainly depends on issues such as the nature of the task being carried out by the team, the team size and the time required for the team, etc. Because of this complexity, many researchers have found a variety of definitions for a team. Salas et al. (2002) defined it as a group of two or more people generally occupying different tasks and skill levels who interact, interdependently, adaptively and dynamically for a common and valued purpose. Similarly, Larson & LaFasto (1989) considered a team to be two or more people looking to achieve a specific performance goal or a recognizable purpose who require collaboration in an activity between the members of the team in order to achieve that final goal. Delarue et al. (2003) defined a team as cluster of employees with at least some collective missions where the team members are authorised to mutually control the implementation of these collective tasks.

2.6.2 Team Importance

Teams are generally recognised as being one of the important factors with which to obtain optimum production economically. George & Bettenhausen (1990) indicated that without an effective team, the value of collective work is diminished and the opportunity to acquire more productive work is missed. Heywood & Jirjahn (2004) also indicated how a team is a vital tool to increase productivity in an organization. Similarly Lynn & Akgum (2003) declared that a team is an essential factor that is significantly related to companies' outcomes. It is noticeable that many companies have made this aspect (i.e. the team) one of the most important principles that distinguishes them from others.

2.6.3 Team Type and Size

Forming a team depends to a large extent on the purpose and nature of the task and on a proper understanding of the task by all the people involved in the team. According to the task type, the team can be classified in six major types: informal (with a social purpose), traditional (in department and functional areas), problem-solving (typically a temporary team), leadership (steering committees), self-directed (small teams) and virtual teams (teams that are geographically spread) (Baker at el., 2006).

The team size and amount of time it requires for a task has been frequently discussed in many past studies aimed at identifying the ideal size of a team, i.e. the team is most effective when it has a sufficient number of team members to perform a task effectively (Guzzo & Shea, 1992). As regards the size of a team, this can be classified into two types: the first of these is a small team consisting of 2-3 people, this size of team is characterized by good interaction but poor diversity; the second type is a large team, typically consisting of 12-13 people which is characterized by good diversity and a variety of opinions and views, however this type of team is weak in its interaction (Poulton & West, 1999). Teams larger than this tend to split into sub-groups. Teams can also be divided according to the time for accomplishing the task. Here, there are two types: a short task time requires hours or days to complete, while a long task time may possibly require for weeks, months or years to accomplish an assigned task (Ehsan et al., 2008).

2.6.4 Team in the Construction Industry

In the technical and organizational aspect of construction projects, teamwork has been applied for a long time. The reason behind this is that, construction projects are composed of various disciplines, and therefore the idea of a team has applied from the beginning of the first phase to the final stage of at project. Consequently, it has become necessary to consider the team during the formation of the organizational structure of construction projects and to establish a suitable location for teams in this structure.

Many researchers have examined the subject of the team in construction projects and have dealt with this field from different aspects according to the direction of their research. Some of the studies conducted have identified results that they anticipated when utilizing a team to complete a project; the optimal use of this method helps to accelerate project achievement in terms of its cost and time. Baiden et al. (2006) examined the level of achievement for nine construction projects. Here, the project managed by the team achieved advanced results when in compared with projects managed individually. Simultaneously, the researchers explored the efficiency of the completion of projects as managed by different forms of teams. They varied according to the cooperation of the teams work within the project, and also depended on the performance of the teams regards the ultimate work goals.

The efficiency of a team depends on many factors, such as the type of communication technology used and the methods of conveying information to others. In addition to this, it depends on the types of relationships between the members. Akgün et al. (2009) observed and studied the performance and efficiency of 163 Turkish firms in the construction industry. They compared them in terms of their products and concluded that emotional capabilities constitute one of the most important factors in the evolution of an organization's work and increase the efficiency of the team within the firm. Their results indicated that emotion has a significant impact on the development of the products, services and processes. In addition to this, it increases the degree of innovation (i.e. the product and processes) exhibited by the team members.

Bresnen and Marshall (2000) found that a genuine desire to participate is a key factor in obtaining successful teams in the construction industry. They also indicated that the existing research fails to examine the social and psychological features of partnering. Consequently, it is also important to be aware of whether an individual is willing to collaborate and deal with others in terms of emotional aspects, rather than merely recognizing success factors. It should be noted that Bresnan and Marshall's work centred on "partners" in the construction industry, who are thus teamed up via contractual agreements. The behaviour of such teams may thus be different to general teams formed by more loose alliance. Tang (2001) reported that in a report submitted to the "Construction Industry Review Committee" in Hong Kong, an improvement in the quality of the relationship between team members and encouraging feedback and mutual adjustment to other groups, such as the design team, led to resolution of particular problems in the construction industry.

2.7 Team Productivity

Productivity is one of the main objectives in the formation of a team and is the key to success in an organization, in addition to other goals, such as quality, time and cost reduction. Productivity for a team in any sector defines the percentage of team output and is divided by team input, here, output could be the financial value and input the materials, worker-hours, etc. (Quambar, 1999). Team members tend to be collaborative and coherent during achieving the task and the final results of this cooperation will be reflected in high productivity (Hare, 2003). With regard to relationships between team members' productivity and their commitment to carry out the task, the studies referred to above indicate that the quantity of team productivity depends significantly on the shared commitments among team members and the amount of clarity as regards the ultimate goal for each team member's task (Bettenhausen, 1991). This study reviewed the principle findings of over 250 studies. On other hand, there is a negative relationship between team productivity and conflicts between team members (Saavedra et al., 1993). The latter study was carried out using 180 undergraduate students who were divided into groups; each group consisted of 3 people who undertook a management task. The conflict between the team members in CMC was less than in FTF since in CMC the members take their time to convey their statements and their reactions are slow. This makes for a good environment when making decisions and so increases team productivity (Bhappu & Crews, 2005). The study was conducted by 64 people who were divided into 16 groups, each group consisting of 4 people. Here, the participants performed a simulated foundation activity in both FTF and CMC.

When comparing FTF and CMC, a considerable amount of research deals with team productivity according to the two methods of communication, the studies include many aspects and domains. Generally, team productivity mainly depends on the task type which the team has to complete as well as the efficiency of the team and the degree of homogeneity of its members (English et al., 2004). The latter study was carried out in 30 cockpits and was divided in 10 categories; each category consisted of 3 pilots who discussed three particular types of tasks: additive, disjunctive, and conjunctive.

There is some argument about which method provides better productivity despite team productivity depending on many factors, as explained above. Some authors have found team productivity in FTF to be higher than in CMC and to have increased the feedback (e.g. Barkhi et al., 1999), see Section 2.4.1. However, others have argued in particular studies that CMC has higher productivity than FTF (e.g. Hewage et al., 2008), see Section 2.5. Closer comparison of these studies shows many key differences, such as sample size, the task type, the field of study (one in manufacturing, the other in construction) and the methodology. Due to these wide ranging underlying differences, it is therefore impossible to say whether FTF or CMC necessarily produces higher productivity and any comparison should be made with care.

2.8 Factors Affecting Team Productivity

Many factors affect team productivity; some of these are clear and obvious such as technical and physical environmental factors, while other factors are hidden, e.g. team behaviour and relationships. Below are the main factors which are likely to have an effect on team productivity.

2.8.1 Team Expertise

The team's expertise is one of the factors affecting team performance in general, and team productivity in particular. Team expertise helps the team members to collaborate, coordinate and share the information in order to obtain new innovations (Jain, 2010). The latter study considers the effect of accumulated team expertise on the innovative production average in the U.S and Canadian biotechnology industry. Here, team expertise is basically dependent on the individual expertise of each member within the team and normally this relationship is positive. An increase in cumulative individual expertise means an increase in team expertise and this leads to an increase in team performance (Reagans et al., 2005). This study was carried out in a teaching hospital and the task concerned a total joint replacement procedure. However, the team expertise has a negative relationship with team errors and team conflicts, although, team expertise correlates positively with the expertise of the best member within the team (Balthazard et al., 2002). This last study was carried on 248 members who were divided into 63 groups in order to undertake a management task.

In construction and design, many researchers have claimed that expert designers perform better than novice' designers at the design stage. Kavakli et al. (1999) found that the productivity score for expert' designers was three times higher than novice designers in the overall design. Kavakli & Gero (2002) asserted that an expert's cognitive actions are well organized and clearly structured in comparison to a novice's cognitive performance; this being divided into many clusters of current actions. A person's perception and thinking when he is an expert in design items is totally different from that of novice. Expert' designers tend to give an explanation for problems according to fundamental principles and establish relations between different situation aspects. Novices' designers, conversely, are inclined to focus on surface characteristics when they fail in a task and create connections between different problems (Ertmer & Stepich, 2005). Additionally, they are also different in terms of their mental and intellectual thinking; expert and novice designers display different mental processes when asked to find a solution to a design problem.

The expert' designer usually spends a significant amount of time analysing an issue and moving toward the generation of a solution after ensuring that he/she has fully understood a situation. As a consequence of this, the designer expert is characterised as having greater efficiency and productivity than a novice designer (Lawson and Dorst, 2009). A novice designer, however, will spend a shorter time analysing a problem and will shift rapidly to the generation of a solution thereby failing to explicate a solution and to search for other alternatives (Rowland, 1992; Perez & Emery, 1995).

2.8.2 Team Member Emotions

Emotional factors can be considered as one of the most important factors affecting team performance, and can also play a significant role in a project's success (Von Glinow et al., 2004). The team's emotions also have a significant effect on a team's status. Hence, when team members are anxious and stressed, their behaviour tends to be more conflictual and less socially cohesive (Barrick et al., 1998). The latter study was carried out on 652 people who were divided into 51 teams to discuss a social task. Conversely, when the team members were comfortable and relaxed, they would deal with conflict points and work seriously in order to achieve the final goal, this being agreed by all the team members (Amason, 1996). This study was carried out on teams in different industries (food processing and furniture manufacturing) and the data was collected using questionnaires.

Over the past few decades, many researchers have studied the relationship between team productivity and the emotions of team members. Emotions can generally be classified into three mains categories: positive, neutral and negative (Ekman, 1993; Kopelman et al., 2006; Mellers et al., 1999). An individual's inner positive feelings and psychological tendencies as well as his or her sense of belonging to a team generate higher productivity for the team members. It was also found that the team members' situations were significantly influenced by negative and positive emotions (Rousseau et al., 2006). Here, the study reviewed the frameworks of teamwork behaviour in the literature as regards work teams and presented a way of integrating these frameworks.

Each type of emotion has a different affect on team performance according to the nature of those emotions; some of these have positive effects on team productivity, the degree of collaboration and coordination, while others have a negative effect. As regards negative emotions, McColl-Kennedy & Anderson (2002) declared that negative emotions such as frustration, irritation and anger reduce the enthusiasm for the team, which then decreases the team's productivity. This study was a survey of sales representatives from a global pharmaceutical firm in Australia and was conducted by completing questionnaires for 139 people. In term of positive emotions, Feyerherm and Rice (2002) found that team productivity increased when the team members had positive emotions and this led to the building of positive relationships when working on specific tasks. This study was applied to 26 customers in a marketing task.

However, the behaviour and emotions of any team member will change over the duration of an experiment, this change is due to multiple reasons, such as the bad behaviour of a particular team member in a team which may upset other team members or change the individual mood of this member. Weiss and Cropanzano (1996) considered changing moods and emotions during a meeting and showed that the degree of satisfaction continued to fluctuate according to the situation of the people while completing the task. This study was carried out by teams from who focused on a social task. Alliger and Williams (1993) also found that the performance of teams can fluctuate in the case of the changing emotions of team members.

Many researchers have discussed the effect of emotional factors in FTF and CMC teams, and some have asserted that an FTF team can be affected by emotional factors more than a CMC teams. This affect may add positive points to a team's performance. However, other authors have pointed out that in CMC, the absence of emotional factors will reduce the interaction between members, thereby decreasing the team's performance. Riordan & Kreuz (2010) studied the affect of two emotion types positive and negative on the behaviour of team members during FTF and CMC communication. They concluded that team members in CMC were less affected by emotional factors than the members in FTF. This study was carried out using 124 people who were divided into teams according to their age groups, but it was stated that the results showed no significant differences due to age difference. The participants were surveyed using questionnaires which contained numerous items about the characteristics of FTF and CMC.

Rice & Markey (2009) also stated that the participants in FTF were more anxious than those in CMC, and therefore it was possible to conclude that the interaction between the participants in FTF was less than for those in CMC. The study was carried out on 80 female undergraduate students who completed a personality assessment and then interacted with a confederate for 15 minutes in FTF and CMC.

The evaluation of emotions is the process of measuring a user's emotional state. Emotions can be expressed by several channels and various features can be analysed to evaluate the emotional state for people, and most of studies focus on the analysis of facial expressions or speech (Cowie et al., 2001). According to Wong (2006), emotional evaluation techniques can be divided into three categories: the first category is that of self-reporting and requires a user to report his or her own feelings verbally or non-verbally; the second category is a physiological measurement, which uses scientific instruments, such as measurement of muscle movements in the Galvanic skin response, electromyography and blood volume pressure; and the third category is that of emotional inference, where the behaviour of a subject is observed during an experiment. In this third category, the data can be collected either directly through real-time observations or via video/audio recordings of users' actions. The current research has adopted techniques in the third category, following the work of Ekman (1993), Kopelman et al, (2006), and Mellers et al, (1999) on the classification of feeling. In total, these researchers have compiled a long list of behaviours that could be observed in a general study. (Appendix E shows the list of behaviours that were actually observed in the current work, behaviours not actually found in the users in the current study have not been listed; see more details in Section 4.8).

2.8.3 Team Cultures

Culture can be considered an important factor affecting team productivity and decision making, particularly since the vast development in communication systems has enabled participants in different places and cultures to work concurrently in order to achieve their goals as a team, through CMC. Here, culture is not just viewed in terms of ethnic and national considerations, but may include many elements such as gender, age, ways of thinking and forms of behaviour (Amaram, 2007). Cultural diversity in a team has become an important point which should be studied and evaluated.

A large amount of research has been undertaken on this point with some researchers supporting culture diversity because of its advantages. Team members composed of individuals from various cultures can introduce many ideas, a wide range of perspectives, many solutions and methods of dealing with issues or achieving goals (Seymen, 2006). A multicultural team can produce and realise new plans and ideas and, additionally, it can be a resource with competitive advantages for the organization (Iles & Hayers, 1997).

Conversely, others also consider culture diversity to be a weakness in the team communication. The diversity of culture in team work may reduce the collaboration and coordination among the team members (Karoc & Kouzmin, 2001). The problem of cultural diversity for team members has had a major impact by reducing productivity and the quality of work achieved by teams. Large differences in cultural backgrounds can create a gap between the team members since their ways of thinking may vary significantly. For this reason, team members should understand each others' culture to minimize misunderstandings (Hambrick et al., 1998). Culturally homogeneous teams, therefore, work more efficiently than culturally heterogeneous teams (Staples & Zhao, 2006).

Notwithstanding this, there are other studies that proved there is no relationship between team performance and the diversity of culture as regards team members. Williams & O'Reilly (1998) have reviewed of 40 years of diversity culture research. They concluded that there is no effect from team member diversity on team performance.

2.8.4 Familiarity and Prior Relationship between Team Members

The familiarity between team members is another point that has been examined when analyzing team performance. Recent studies have revealed that familiarity not only improves team performance but it also helps team members to overcome the difficulties generated from weak collaboration or task complexity (Huckman et al., 2009). Additionally, there is a positive relationship between social ties and the level of trust. If this relationship increases the probability of reaching an agreement it will be better in comparison to a team having strangers as members and them having a weak relationship (McGinn & Keros, 2002).

Many authors have praised prior relationships between team members because of their numerous positive aspects which increase the team's performance. In addition to this, previous working experience among team members enables managers to assign tasks efficiently and helps team members to collaborate and coordinate where there are specialized responsibilities (Reagans at el., 2005). The benefits of shared work with the same team members can lead to an increase in the quantity and quality of shared knowledge (Monteverde, 1995). Additionally to this, common and recurring collaboration and interaction help team members to build new communication channels and to establish a common language which they can all understand (Narayanan et al., 2009).

In contrast, some authors have declared that too much of a prior relationship and team familiarity can lead to a decrease in a team's productivity and has certain disadvantages, especially if team members have worked together for a long time (Katz, 1982). Overestimating familiarity between team members may lead to an increase in negative and uncivil behaviour which reflects on the total team performance and increases conflicts (Porath et al., 2008).

Past studies have classified teams according to the prior relationships of their members by comparing the teams to see if they consist of acquaintances, friends or strangers. These studies have concentrated on the levels of communication in different types (Gruenfeld et al., 1996). There is a difference in the level of communication between teams where there are friends or the teams consist of strangers. In addition, the communication level is related to the type of these relationships between teams' members, which can be divided into formal and informal relationships (Jehn & Shah, 1997)

Familiarity is different in FTF and CMC and, there are numerous views about familiarity and prior relationships. Some researchers have indicated that familiarity decreases when team members are distributed geographically since there is a weakness in their sharing of knowledge. One of the main reasons why familiarity in FTF is better than in CMC is the poor quality of communication in the latter which may lead to a lack of mutual knowledge, so reducing any sense of familiarity (Cramton, 2001). This last study was carried out using 13 geographically dispersed teams on three continents; each team consisted of 6 members, all of whom were undergraduate students in business.

Conversely, others scholars have claimed that familiarity and the relationship between team members can become strong and effective over time in CMC in contrast to FTF

(Walther, 1995). On the other hand, the team members in CMC tend to get to know each other through discussion by asking additional questions to identify particular members' personalities, this occurring less in FTF communication (Tidwell & Walther, 2002). This last study was conducted using 158 students in a private American university, half of whom were females, to discuss a social task in FTF and CMC.

2.9 Degree of Collaboration (Collaboration Index)

Collaboration is something which in concept is well understood but the determination of a metric which can be used to assess the degree of collaboration is something which is far more challenging. Degree of collaboration represents the amount of interaction between team members to achieve an enhanced shared understanding and enable all team members to fully participate and accomplish the mission. The degree of collaboration for any team depends on several key factors such as emotional interaction, cooperation comprehension, shared vocabulary and inter-personal interaction.

2.9.1 Importance of Degree of Collaboration

The degree of collaboration is one of the most important variables which should be considered during an evaluation of team performance because this reflects on the efficiency of the team when working towards its final goal. This applies whether the team uses FTF or CMC (Kaushik et al., 2000). Collaboration is an important factor to the success of any team mission; therefore there have been various attempts to find metrics to determine the collaboration level between participants within a team (Barratt & Oliver, 2001). Measuring collaboration level assists with the identification of the shortcomings of a given collaboration and helps to find the possible initiatives to remedy them. The measurement of collaboration levels also helps people to determine the benchmark for the current collaboration level and compare it with any new collaboration performance in the future (Simatupang & Sridharan, 2004).

2.9.2 Previous Work on Degree of Collaboration

In spite of the collaboration being widely studied in many different fields, the work has not produced any standard, agreed method for the calculation of the degree of collaboration. Simatupang & Sridharan (2005) have developed a collaboration index that computes the collaboration level in a supply chain relationship. Their index depends on three factors, these being decision synchronicity which refers to joint decision making in planning such as future planning, market demand, etc, operational contexts such as shipping products and refilling products in the stores, etc, amount of information sharing and incentive alignment which refers to the degree to which chain members share costs, risks and benefits. The collaboration index is basically the mean of scores for the three factors as evaluated for each participant in the team as shown in the Fig. 2.3, they used Likert scales (1-5) (Likert, 1932) to assess the degree of collaboration for each member. A high score in this index means this member has high level of supply chain collaboration.

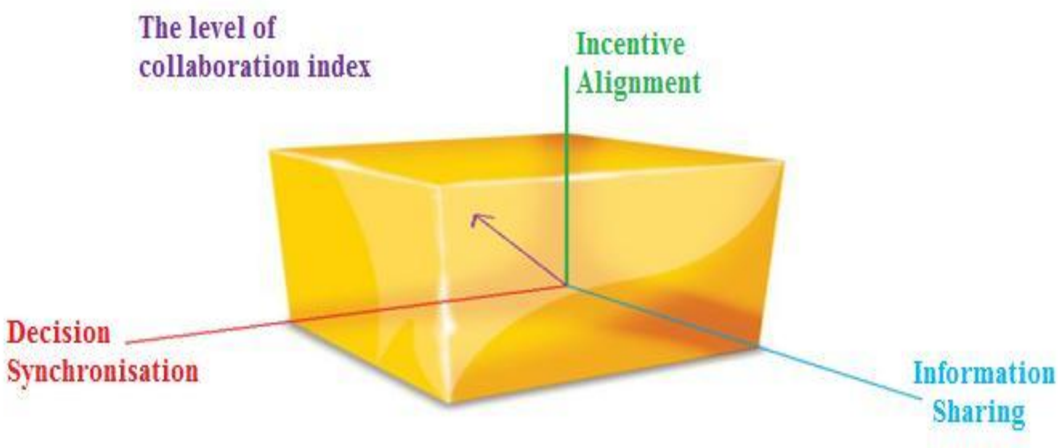


Figure 2.3: The concept of the collaboration index (Simatupang & Sridharan, 2005)

The collaboration index measure has been adopted in some organisations, but the method appears to be very subjective and depends on the personal assessment and is therefore not very reliable.

Semar (2005) studied the degree of collaboration between student team members working, using management software. He claimed the degree of collaboration depends on four components:

1. “Synthesis”, which concerns the degree of agreement in a team and is evaluated with a “voting tool” on the summary decisions of the team in a discussion.
2. “Independence”, which concerns the team’s ability to work without the instructor, and is evaluated by number of occasions, the instructor interjects with corrective information/instructions in the team discussion.
3. “Interaction”, which concerns the flow of discussion, and is evaluated by the number of “stand-alone” comments, i.e. comments made by a participant which are not then responded to by other participants.
4. “Participation”, which concerns equal sharing in the discussion, and is evaluated by the total deviation of the number of comments made by participants, from the ideal split (i.e. all participants in a team making exactly the same number of comments).

All four components have a normalised score, and the degree of collaboration as shown in Figure 2.4 is defined as a 4x1 vector with entries being the four normalised scores, and is visualised as a quadrilateral on an *x*-*y* plot. The ideal collaboration is thus $[1\ 1\ 1\ 1]^T$ and is represented as a rhombus with vertices at 1 on each of the four axes.

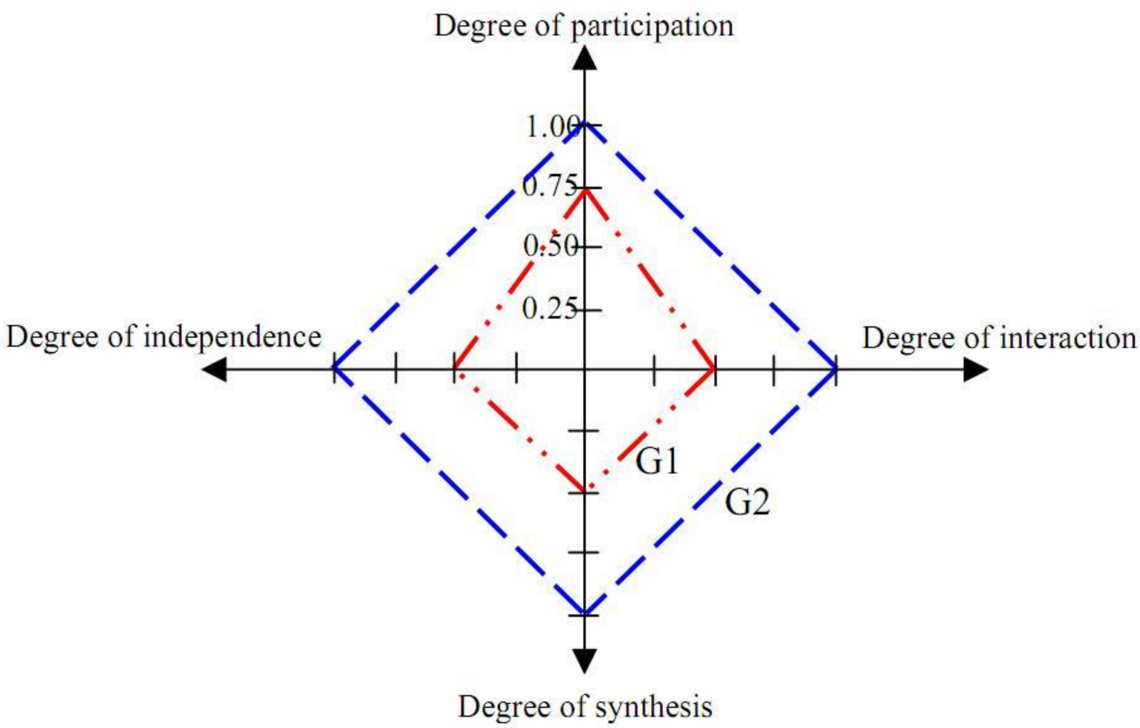


Figure 2.4: The concept of degree of collaboration (Semar, 2005)

This method has been developed for use with learning environment task which are very different to design task. Also, it is obvious that the role of the instructor in this method may negatively impact on the degree of collaboration. Due to the above particular shortcomings, and the fact that the tasks and subject matter in the present investigation were significantly different, this research adopted another method for calculating the degree of collaboration, by resorting to experimentally determined metric quantities such as number of exchanges, number of words and time measurements.

2.10 Team Design Quality

Design quality has many meanings according to the domain being considered. In the construction industry, it can be defined in terms of the effective and ideal design that meets all the stakeholders' requirements concerning cost, time, safety and quality (Abolnour, 1994). The continuous tracing of customer requirements as regards service quality and an acceptable cost are fundamental issues for any project in order to achieve success (Wen-Baw, 2007). During the design process, it is necessary to input correct and accurate construction knowledge so as to avoid any potential problems in the final design (Mc Cullouch, 1996). The weakness and poverty of the construction knowledge during the design phase may hinder the project implementation by resulting in the project exceeding the budget and schedule time (Trigunarsyah, 2004).

Design quality can be considered as one of the important elements that makes projects more successful and well developed since design, in general, is a major step in the construction process. Additionally, correcting and dealing with errors at an early stage, especially at the design stage, can help with avoiding future problems and, may have consequences for the project's implementation. Improvements in any engineering project can be realized by considering four elements: design, the construction methods, the management approach and procurements (Griffith & Sidwell, 1995). The quality of the design should be at a high level when there is shared information that is available and understood by everyone working on the design. This also depends on the equality of the information as well as whether or not it is successfully or punctually passed around the design team at different stages in the design phase (Pulaski & Horman, 2005).

Some studies have concentrated on the deviations in the design and construction stages and have revealed that most of the deviations in the project budget and schedule deadlines are related to inferior design. Burait et al. (1992) claimed that 78% of the total number of deviations is related to design deviations and constitutes 79% of the total number of deviations in project budgets. Andi & Minato (2003) further revealed that contract modifications are most affected by three main factors: design deficiencies, unidentified site conditions and requested changes by the client. In addition to this, they asserted that 56% of all contract adjustments are requested to correct design weaknesses. Similarly, Lutz et al. (1990) claimed that more than 50% of the change orders relate to defective design.

2.10.1 Factors Affecting Design Quality

Many researchers have studied the factors affecting design quality. Deficiencies in design and weaknesses in information transformation between parties at the design stage can cause a large proportion of reworking and result in escalating costs. Further to this, from the financial side, the reduction in the design fees for the designer's staff and the limited time for the design process can clearly lead to a reduced design quality (Love et al., 1997).

Many factors affect design quality, some of which relate to construction industry issues, such as the nature of the design, the budget of the project and the standard requirements of the product. Additionally, there are other problems relating to the parties' relationships (Egan, 1998). However, other factors appear to be more influential and closer to project components, such as the project time, project cost and the method of the project management (Tilley et al., 2002). The expertise level of the designers is another factor affecting design quality and may sometimes be the most influential factor. Further to this, a lack of experience on the part of the designer's staff, poor knowledge about the full design details in addition to a lack of staff training concerning new technologies in design (and how to use them) will also affect design quality (Baigent, 2000).

2.10.2 Design Quality in FTF and CMC

The design sector, like other sectors, has witnessed an enormous technological revolution and has been greatly helped by the aspects of design developments in the construction industry. These technologies have provided designers with active tools with which to communicate and with which they can collaborate during the design process. Hence, a new development team design can become more proactive in comparison to a traditional design process in FTF. There are few studies which have compared design quality in FTF and CMC since most authors have studied design quality as a component within team performance in general. Collaborative design has therefore become a main goal for many design companies due to its many advantages in overcoming the difficulties faced by design staff. It has also become a good technique through which the teams can increase their experience by mixing with different people from varying disciplines.

Collaborative design means working with parties from different disciplines such as contractors, designers, suppliers and customers, in order to discuss, modify and solve problems in design. Some authors have indicated that CMC is better than FTF from the point of view of design quality. The traditional design process in FTF is mainly based on the personal skills of team designers and therefore the final product of collaborative design depends on a limited amount of shared information and skills. However, in CMC, the design process has witnessed dramatic changes in teams as regards knowledge accumulation and shared information. Hung-Wen et al. (2010) found this is because it deals with a vast amount of information and includes much more complex interpersonal communications. Tang (2004) states that CMC therefore makes the design product more compatible with the client's requirements and provides better quality. Accordingly, some companies and clients tend to use CMC in design instead of FTF since this approach gives the design product more quality and results in greater efficiency in comparison to FTF (Kimble et al., 2000). Moreover, the design process in CMC offers an extensive amount of information and knowledge sharing and, hence, a greater exchange of this information means improvements in the design of the product so leading to an increase in the design quality (Cross & Cross, 1995).

2.10.3 Design Quality Measurement

Design quality measurement can be considered as a complex issue because it is difficult to quantify since it comprises both objective and subjective components, which depend on the subjective preferences and opinions of the evaluators (Castro-Lacouture &

Ramkrishnan, 2008). Nonetheless, a few methods have been used to measure design quality, as surveyed by Castro-Lacouture & Ramkrishnan (2008), e.g., “Bishop’s method” Bishop (1978), “Harmony method” Smith (1987), “Modified lens model” (Gifford et al., 2000), and “Design Quality Indictor (DQI)” (Gann et al, 2003).

Bishop’s method (Bishop, 1978) is based on evaluation by the users (and evaluators) answering a series of questions relating to three factors in buildings: function, form and economy. A score of 1 to 10 would be assigned for the three factors and the building design quality is obtained by calculating the area of the triangle formed by plotting the score of the three factors on a tri-axis graph. DQI (Gann et al, 2003) on the other hand, is one of the most widely used methods to measure the design quality of the building. It is used as a tool to assess design quality in construction projects with the purpose to summarise and organise stakeholders’ evaluations of design quality. It is done by completion of a questionnaire by all the project stakeholders on each item in the project. Analysis of this questionnaire gives an indication of design quality, from concept to construction to occupation and maintenance. The questionnaire consists of three parts, building functionality, build quality and impact of the building.

The current research had not adopted any of the methods in the literature because in most of the methods, there is a need for evaluation by experts in design, and the current research had not access to such experts. In current research, a simple form was thus devised, evaluating the extent to which the design output from each team in FTF and CMC satisfied “fundamental requirements” and “usability requirements” (see Section 3.4.4 and Appendix D).

2.11 Non-verbal Communication

This section starts with an introduction to the definition of communication and, then focuses on the components of non-verbal communication related to this research which are body movements (include facial expressions), eye contact and changing voice emphasis. Non-verbal communication is of importance in this work because the use of CMC places severe limits of the transmission of non-verbal cues.

2.11.1 Non-verbal Communication Definition and Importance

The communication process can be defined as the transmission of information between the sender and one or more recipients. The information is partially transmitted by verbal communication but non-verbal communication (NVC) also is a significant factor. Non-verbal communication is extensively regarded as the transfer of meaning without the use of words (Butt, 2011). There are many components of the non-verbal communication described in the literature such as body movement and posture (which include facial expressions), gaze and eye contact, touching, symbols and info-graphics, tone of voice and personal appearance which can all be significant during FTF communication and hence, potentially, can have an effect on responses and behaviour (Gray and Moffett, 2010; Hall, 1984).

There is an extensive body of research on non-verbal communication (NVC) and only the more salient features will be discussed here. Argyle (1975) has asserted NVC helps people to express their emotional states, by transmitting personal information and interpersonal attitudes and hence helps to organize social interaction. Knapp (1978) stated that the term NVC is used to describe all human communication activities which don't use either written or spoken words. In addition, social psychologists confirm that more than 65% of the total information exchanged in FTF occurs by means of NVC. Knapp and Hall (2007) stated that NVC involves three factors: environmental conditions, physical characteristic and the behaviour of the communicators, all of these are restricted in collaborative virtual environments.

Nowak et al (2005) stated that communication via CMC is quite depleted emotionally because of the lack of richness for non-verbal communication which increases the degree of interaction in FTF. Hall (1984) claimed that almost 90% of FTF communication is non-verbal while Wiener and Mehrabian (1968) stated the percentage of NVC is 93%. Mehrabian (1981) discovered that in general the message will be transmitted by the three general communication aspects in the following proportions: 7% for the spoken word, 55% for postures and 38% for pitch, volume and intonation. Whatever is the precise percentage of the total, NVC is a significant feature in human communication.

NVC is an effective method of conveying information about personal emotions without any need for additional verbal explanation, although often NVC occurs without the transmitter being aware of what messages they are conveying or indeed being able to control the message content (Guye et al., 1999). Communication partners use NVC for increasing their visibility and to clarify the points that they are trying to convey (Gergle at el., 2004). Additionally the greatest use is made of NVC when the degree of interaction between the partners is at its highest level (De Waal, 2003). NVC helps people to coordinate and collaborate to achieve their involvement objectives (Tooby and Cosmides, 1996).

Kinesics science is used to study NVC face and body movements. It identifies five kinds of movement: “emblems” (body movements in place of verbal phrases), “illustrators” (body movements accompanying and reinforcing verbal phrases), “regulators” (action relating to direction of communication), “affect display” (facial movements to display emotions), and “adaptors” (unconscious gestures, not necessarily directly connected with what is being said, but could be related to negative feelings). Kendon (1994) mentioned that most NVC experts consider body movements, eye contact, facial expression, gestures, and touch communication as being the principle components of NVC. Additional factors such as cultural differences are also important and can be an issue during communication between people from different backgrounds. Axtell (1993) states that there is a small number of emblems which can be used across different cultures i.e. there is a limited number of universal movements.

As stated above, the literature on NVC is large and the following have been chosen to represent the more salient features that are more immediately relevant. Sumi and Moriyama (2010) classified body actions features for both teachers and students in classrooms during lectures according to the taxonomy of Ekman and Freisen (1969) and they concluded that the emotions exhibited by the teachers have an ambiguous impact in spite of the accepted wisdom that displaying emotions better informs their audience. Kraut & Johnston (1979) discovered that the attention of an audience can be significantly enhanced by the speaker smiling in appropriate situations. Ekman (1997) points out that gestures can express intention, or leak emotions, or communicate a specific single cultural signal, in the absence of language, which could give additional key information to listeners.

In the construction sector, there has been no previously reported work on the impact of NVC on team productivity, for any stage of construction or design, and particularly relevant to this work, the design stage. Team productivity is affected by emotional factors or individual personality (Rousseau et al. 2006) and these are the aspects mainly conveyed by NVC. A discussion between team members is strongly affected by traits relating to character, behaviour and personal motivation (Kleinman and Palmon, 2001). Other factors such as humour, flexibility, degree of cooperation, and understanding of the problem have an effect on decision making and the quantity and quality of team productivity. They can be considered as significant factors while behaviour such as general authoritarianism or related forms of domineering behaviour lead to decreases in team productivity for many of team members and tend to restrict the productive output to just one or two members of the team (Mchoskey, 1995).

2.11.2 Non-verbal Communication Components

This section defines and expands on the non-verbal components studied in this research which are body movements (includes facial expression), eye contact and changing voice tone. This section considers how these components differ between people during communication.

2.11.2.1 Body Movements (including facial expression)

Body movements are the main part of the NVC and represent all the movements made by our bodies. These movements may provide clues as to the attitude or state of mind of a person. For example, they may indicate attentiveness, a relaxed state, pleasure, and amusement among many other cues (Butt, 2011). Body movements include many types of movements e.g. using the head, hands, arms and lower part of the body. The internal emotion of a speaker can be reflected by observing his/her hand movements when talking (Lesikar and Flatley, 2005). People use body movements in their everyday conversation, and this is considered a definite part of their communication system (Ross, 1977). It should be noted that the current research concentrates on movements only of the upper body, since the participants all sit at a desk (more details of body movements in Section 2.11.3).

Facial expressions are an important part of human communication and some facial expressions occur universally among humans and are therefore understood by all. Facial expressions reflect the personal demeanour of the person and mirror the emotions expressed in people’s comments, as shown in Fig. 2.5, thus forming a second source of information to support the spoken words (Knapp, 1978). Facial expressions can be understood across cultural differences even when there is a language barrier. Most people are unable to hide their feelings, and their emotions manifest themselves as certain facial expression (Matsumoto et al., 2005). There are many other types of body movement beside facial expressions which are independent of language and hence some NVC expressions do not need to be associated with any verbal events (Aboudan and Beattie, 1996).

Facial expressions are a significant aspect of NVC. Brody and Hall (2000) discovered that males and females differ in their expressivity and use of facial expression, with women tending to use facial expressions more often, and they also tend to hide expressions of negative emotions. Ekman (1984) concluded that an important factor affecting the analysis of facial expression is the difficulty of measuring responses to emotions which produce expressions of short duration. Frank (1997) suggested a new approach by using computer-based methods to record these short emotional expressions by comparing them with standard features of emotions. Using this method it is possible to analyse many expression in a short time. Curhan (2007) used a new computer based visual imaging approach to capture and analyse short duration expressions.

Ekman et al. (1972) divided universal facial expressions into six categories with these being Anger, Sadness, Surprise, Fear, Happiness and Disgust. This classification is now widely accepted. Ekman & Friesen (1978) created a facial action coding systems (FACS) which helps the analyst to record all facial expression according to predefined code. Wagner (1997) has submitted two approaches for analysing facial expressions. The first is based on metrics of facial movements. The second is subjective judgements made by the observer in response to questions.

Figure 2.5: Different patterns of facial expression (Facial expression meaning/Image)

2.11.2.2 Eye Contact and Changing Voice Tone

Eye contact and changing voice tone represent various NVC components which reflect the state of a person during a conversation. For eye contact, Mason (2003) mentioned that the people use eye contact during a conversation to indicate confidence sincerity and authority. Miller (1988) asserted that the amount of eye contact used by a speaker reflected on their degree of credibility and honesty. Wainwright (2003) states there are six tasks for eye contact: dominance, requesting information, controlling interaction, showing attention, giving feedback and politeness or a lack thereof. Changing voice tone during a conversation has many functions, for example, emphasizing, conforming the importance of some passage of speech, or trying to attract the attention of the listener. Vinciarelli (2009) postulates that changing the voice tone is used to reflect the personal state such as anger or disagreement. Ververidis & Kotropoulos (2006) found that the voice will be at high intensity for emotions such as happiness, anger and surprise while it will be lower in intensity when the person feels sadness, disgust and fear.

2.11.3 Group Analysis to Non-verbal Communication Components

The analysis of the NVC during the experiments was undertaken using techniques based on the work of Efron (1941), Ekman and Freisen (1969) and Body Language Classification (2010). The techniques are not new and have been used by many authors. The technique has been divided the movements for five main categories as following.

2.11.3.1 Emblems Movements

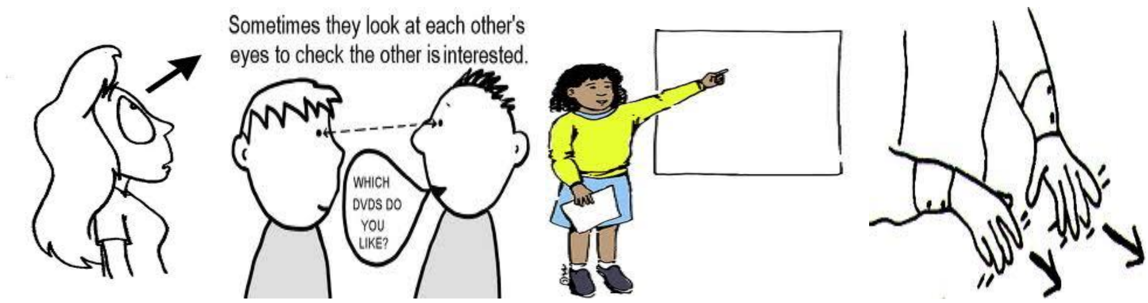
Emblems are defined as having a direct verbal equivalent to the particular movement such as good bye being substituted by a wave or hand shake.

2.11.3.2 Illustrator Movements

Illustrators are defined as a group of movements that can be used to describe a specific event or illustrate a specific idea as shown in Fig. 2.6, for example, the use of hands during speaking. Typical examples include pointing out something, using the hands for descriptions (e.g. making gestures while speaking), adding of emphasis to speech by movements, etc.

Illustrator can be used for many purposes for example.

- Emphasizing speech or individual words by movements.
- Emphasizing speech by changing voice tone.
- Explaining ambiguous words by body movements.
- Reflecting emotion by body movement.
- Attracting attention to the speaker by movement



Look at | Eye contact | Pointing out | Hand for description

Figure 2.6: Illustrator movements

2.11.3.3 Adaptors Movements

Adaptors are defined as movements that help the participants to adjust in the working environment or to satisfy some personal need as shown in Fig. 2.7, e.g. for comfort or security. These could be necessary movements in the progress of work, e.g. moving of upper body from talking to computer typing. These movements could also reflect the emotional state of the person during a conversation, e.g. wriggling on the chair, scratching, chewing a pen, etc, and they do not necessarily have a communicative meaning, i.e. they could be just a display of a personal habit. It is also true that a particular adaptor action in a specific instance could be placed in another category. Some examples of adaptors include:

- A vertical head nod generally means the acceptance of the idea.
- A horizontal head shake generally means refusal of the idea. It should be noted that in Western culture a vertical head nod shows agreement and the listener is interested and is encouraging the speaker while horizontal head shake means either disagreement or even disbelief (Wolven & Coakley, 1996). However, in some cultures such as Bulgariaor, Bengal and Turkey, a nodding head means disagreement (Imai, 1996).
- Hand(s) on cheek, chin, head, forehead, and interlocking fingers means thinking and making a decision.
- Folded arms across the chest mean the listener is not comfortable with the speaker's idea.
- Hand(s) covering mouth means embarrassment.
- Hand(s) on thigh means relaxation.

- Touching in the nose during speaking, shows uncertainty or hesitancy.
- Touching the nose during listening means this person is thinking about other ideas and is not interacting with the speaker.

These above movements have been established by (Efron (1941), Ekman and Freisen (1969) and Pease (2004). Generally, these movements are universally valid but there are some cultural exceptions (and noted above).

Hand on chin

Hand on cheek

Hand on forehead

Hand on head

Interlocking fingers

Folding arms across the chest

Hand on mouth

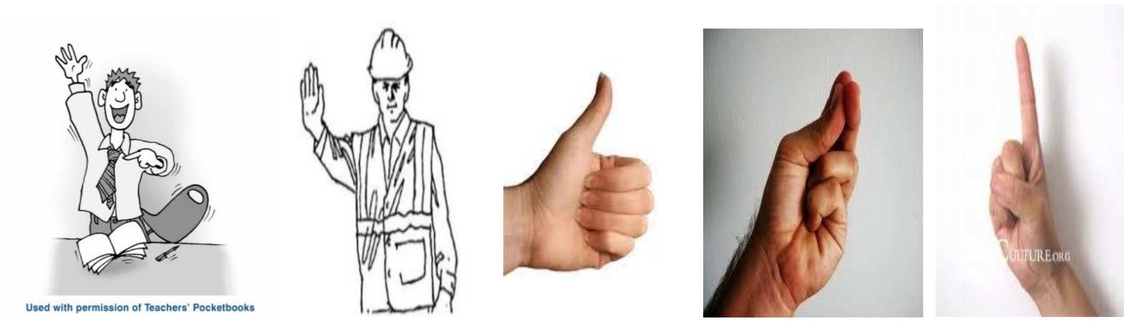
Hand on thigh

Figure 2.7: Adaptors movements

2.11.3.4 Regulator Movements

Regulators are defined as a group of movements which are use to control the discussion, as shown in Fig. 2.8, for example, hand up (i.e. to interrupt the speaker), holding a hand up to refuse, thumb up, using the hand to stop (i.e. prevent speaker from completing his/her speech), using hand to wait, threatening by use of the index finger. These movements can be used for many purposes for examples.

- To stop the conversation.
- To refuse the speaker's idea.
- To allow the user to speak.
- To draw attention to other people.
- To encourage other people.
- To threaten other people with regard to some actions.

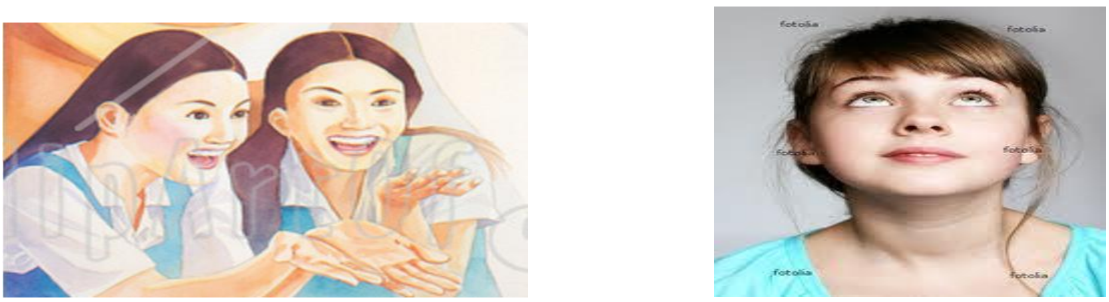


Hand up   Hand to stop   Thumb up   Hand to wait   Threatening Index

Figure 2.8: Regulator movements

2.11.3.5 Affect Display Movements

Affect displays are defined as conveying emotion by movement for example smiling or laughing, looking upwards, looking around as shown in Fig. 2.9.



Smiling and laughing   looking upwards

Figure 2.9: Affect display movements

2.12 Summary

This chapter is a detailed theoretical review for this research. Starting with a general introduction of communication and collaboration in the construction industry and what are the important systems which used for collaboration purposes and how the degree of collaboration in construction industry has been calculated in some cases. Regarding FTF and CMC meetings, this chapter introduces a general comparison between FTF and CMC and it focuses particularly on the construction industry, this comparison includes different aspects such as efficiency, performance in addition to that it summarized the advantages and disadvantages for each method. Additionally it explains the team concept in the construction industry and the important factors which affect team performance, such as team expertise, culture and background, emotional factors and familiarity. Design quality for the team has been studied and the differences between this quality in FTF and CMC. Finally this chapter concentrates on non-verbal communication in FTF meetings and classifies these movements for the main categories such as Emblems, Illustrations, Regulations, Adaptors and Affect Display.

This current research deals with some of the deficiencies and conflicts found in the previous studies in the communication and collaboration area. This research compares between FTF and CMC for design tasks in many aspects which include communication quantity (number of words), nature of time used, team behaviour profile, team productivity (this research studies four factors affecting team productivity), degree of collaboration and how is this best measured. The work also considers design quality in two methods and finally explains non-verbal communication in FTF and what is the relationship between non-verbal communication and team productivity.

Chapter 3

Research Methodology

3.1 Introduction

This chapter explains the research methodology used in this research and provides details about the procedure of the experiments as well as their analysis. The chapter is divided into five sections:-

1. Section 3.2 presents a general overview of the research methodologies used in the research and a justification for the type of the methodology employed.
2. Section 3.3 considers the requirements needed for the experiments, such as team members, the model/documents, the tasks, the hardware and software.
3. Section 3.4 explains the procedure of the experiments, including the details of the experiments, their recordings, transcriptions/coding and an analysis of the results (including statistical analysis).
4. Section 3.5 illustrates Revit Architecture (i.e. the collaboration software is used in this research); this illustration includes Revit Architecture features with a particular emphasis on those used for this research, the project collaboration, worksharing terminology and the enabling of worksharing in Revit.
5. Section 3.6 explains the operating system software (Windows Server 2003) which has been used to make the hardware and software work effectively.

3.2 Research Methodology

Science can be divided into many separate fields, each being characterised by its own distinct types of research methodology according to the nature and details of its research. The style and nature of these methodologies is often based on the theories relating to a particular domain and can be either quantitative or qualitative, sometimes combining aspects of both. Quantitative methodologies include studying and analysing data that has been collected from an experiment and searching for proof of a previously developed hypothesis; qualitative methodologies, however, aim to discover, describe and understand a specific phenomenon by using documents, interviews, questionnaires and the observation of people behaviour, etc (Lee et al., 1997).

The research described in this thesis is empirical since a systematic, experiential basis is used to achieve its goal, when the research problem has been realised, the existing literature reviewed, the data has been analysed, conclusions have been drawn and recommendations have been made (Creswell, 2005). The methodology adopted here involves:-

- A theoretical study of previous research in communication and collaboration, particularly research that focuses on communication by networked computers, i.e. Computer Mediated Communication (CMC) which is closely related to the field of Computer Support Collaborative Work (CSCW). Indeed, the two fields are sometimes difficult to distinguish, but they are differentiated by Garza (2011) as: CSCW takes place when technology is used for any type of work while CMC takes place when computers are used for the interaction between humans.
- Carrying out experiments using a simple building model with the aid of users (volunteers). These experiments have been divided into particular methods: - Face to Face meetings (FTF) during which the users collaborate FTF on a design engineering task which requires them to solve the problems in the model. Computer Mediated Communication (CMC) is also employed during which the users collaborate using CMC on a design engineering task, (this task being different from the FTF task) by using networked communications for solving the problems in the model. For both FTF and CMC tasks, the users are required to discuss and amend aspects of a building, these being divided into many sectors, e.g. the exterior walls, the interior walls, roof, floor, architecture and site design, electrical work, mechanical and plumbing fixtures, etc.
- Recording the experiments’ details, transcribing the results and devising and using a coding system to extract further information, then analysing the results for both FTF and CMC to extract the most important parameters, such as the number of words, team and individual productivity, time divisions, observations of the emotional behaviour of the users, the degree of collaboration and team design quality. In addition to this, the analysis of non-verbal communication (NVC) results for FTF and classifying the NVC movements into their main categories, as well as finding the relationships between these movements and team productivity.

3.3 Experiments, Requirements and Challenges

This section clarifies the requirements necessary to achieve the experiments undertaken in this research. As regards the experiments, the requirements can be divided into types, such as the people (the team users used to achieve the engineering design task), the tasks, the model and documents, sets of cameras and computer systems which consist of a key part (server) which has specified software for collaboration associated with a group of computers in different locations. The main activity of this system is to support collaboration work between users in CMC. Listed below are the full details of these requirements.

3.3.1 User Teams

Participants have constituted a vital resource in undertaking the experiments in this research because the results entirely depend on their discussions and productivity in achieving the tasks for both FTF and CMC. Forty users participated in each FTF and CMC experiment. Finding volunteers was one of the most significant challenges. It was difficult to find people willing to spend the extended period of time required for carrying out the experiments. Another barrier was that the research needs volunteers with various expertise levels and this point increased the difficulty to get volunteers at specific level of experience. Most of the volunteers in this research have come from informal relationships such as friends, students, colleagues and so on. To get 40 people from industry, and to get them to turn up in relevant pairs, would have been very difficult, if not impossible because they need to commit several hours of their time.

In addition to the above mentioned 40 users, there were nine individuals used in the “single user” experiments. There was only one principal controlled factor in the experiments, namely the expertise of the teams (see the five categories in Table 3.1) and hence individuals with the appropriate expertise were sought in order to obtain a balanced number across these five categories. Other factors, such as the prior relationships of team members, the emotional profile of the users, and whether there is a cultural difference between them, were not controlled. The sample size in the current work was thus controlled and balanced according to team expertise only, and thus it could be argues that the results when considered in relation to the other factor might be affected by an imbalanced or inadequate size, or lacking proper control sample. Nonetheless, useful indicative results did emerge on these other factors and thus they have been included in the discussions of the current work. Since team expertise is the only factor with a controlled sample size, it is possible for bias to be present when the results are studied in relation to any other factor.

Most of the users were PhD students at Cardiff University, these being from different countries and cultures, namely Iraq (14 users), China (7), the United Kingdom (4), Iran (4), Malaysia (3), Kuwait (2), Greece (1), Lithuania (1), Nigeria (1), Libya (1), India (1) and Indonesia (1). Additionally, most of them have experience in design aspects and the construction industry. Another challenge was that none of the users in the research was familiar with Revit and therefore, before the tasks could be performed, they all had to be given identical training in Revit and this also needed extra time. The users were divided into teams of two people, with twenty teams overall. One of the main reasons why the team size was two people is that the simplest possible configuration, and it is important to firstly establish the characteristics of a simple team before introducing further complexities from larger teams, which would also have greater number of team interactions to consider. It was also difficult to obtain a good number of volunteers for the experiments, and thus teams of two allowed the largest number of teams (and thus data points). Furthermore, the task required of the teams was simple enough so that two people could carry out and complete the task.

The twenty experiments used in this research, whether in FTF or in CMC, were made up of four teams of users in each of the five categories of team expertise; thereby giving an even spread of data across the range of experience. There was a mix of users in these experiments, where the “novices” (16 out of 40 users), “Junior expert” (8) and “Expert” (16) were individuals with no, some, or a lot of association and previous experience in engineering, design, or the construction trade. Furthermore, seven out of 20 pairings were complete strangers to each other and seven of the 20 pairings were with users from different cultural backgrounds. Furthermore, 33 of the 40 users were male. There was thus a fairly good variety of both “stakeholder types”, as well as of personal familiarity, in the list of users, and thus good confidence that the results had not been particularly polarized by these effects.

In addition to the experiments in FTF and CMC, which involved two users collaborating on each task, nine additional experiments were conducted in which a single person working alone did the FTF task, with three experiments for the same task (i.e. FTF task), for each type of user, 3 for Expert (two from Iraq and one from China), 3 for Junior expert (one each from China, Mexico and Romania) and 3 for Novice (one each from Iraq, Iran and Malaysia). These experiments were conducted under the same conditions as the team experiments (i.e. the identical task and time for each experiment). The reason for these additional experiments was to establish the differences between productivity and design quality, with the designs from teams and single users.

In order to maintain consistency and to avoid contaminating the experimental results, both team and single users were told beforehand that they were to conduct the experiment on their own, i.e. no communication would be allowed between the users and the present researcher. Nonetheless, some single (and very seldom, team) users would still call for the attention of the researcher during the course of the experiments. Occasionally, the query involved simple Revit program operational issues (e.g. the user has lost a window and could not re-open it), and in such cases, help would be provided, though without any speaking to the users. At other times, the help sought would relate to the task itself, and strictly no answers were provided for these queries; instead, the users were "waved away".

Table 3.1: Type of team expert according to level of expertise

Expertise Level	Acronym	Description	Number of Teams
Expert-Expert	**E-E**	Both users have a high level of experience in the design field (typically > 5 years post Engineering graduation).	4
Expert-Junior expert	**E-Je**	One user has a high level of experience, but the other user has only a moderate level of experience (typically an engineering graduate but with < 5 years of experience).	4
Expert-Novice	**E-N**	One user has a high level of experience but the other is a novice who is not an engineering graduate, and has not any experience in construction or design.	4
Junior expert-Novice	**Je-N**	One of the users has moderate experience but the other is a Novice.	4
Novice-Novice	**N-N**	Both users have no or very little experience in construction or design.	4

3.3.2 The Model and Documents

The model is a 3D geometric model in Revit which represents a small and simple residential building (Middle Eastern style) as shown in Fig. 3.1. The model (house building) was chosen because it is very simple and was understandable for different users at various levels of expertise, particularly users of the Novice type with no experience in the construction field. It consists of two floors with 3 bed rooms, a kitchen, a bath room, living rooms and a W.C. Additionally, there is a large fenced garden surrounding the building. The model is divided into 8 “worksets” (A workset in Revit is a specified sector of the model, each workset represents various elements of the scheme such as electrical, mechanical, etc., for example “Exterior wall” workset would contain walls, windows and doors). The Revit model contains the full details of the project, e.g. geometry, materials and a bill of quantities. Limitations and constraints were placed within the model in order to make the users consider factors such as cost, time and quality.

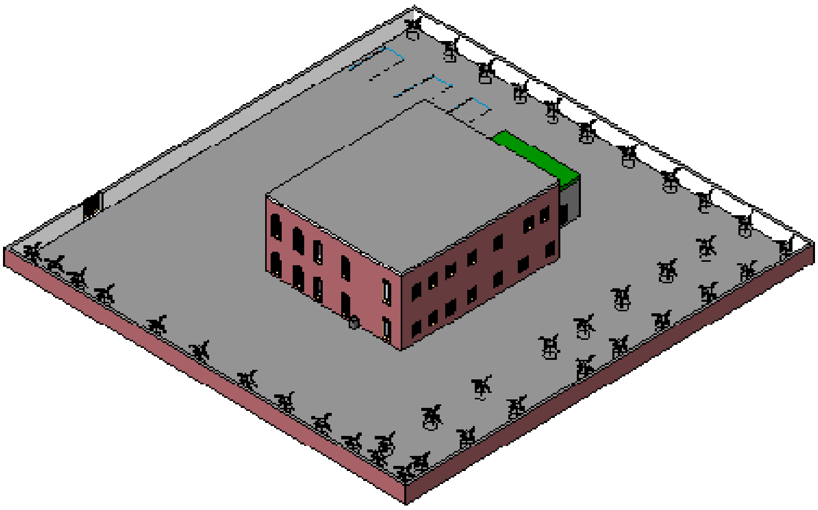


Figure 3.1: An external view of the Revit model (see Appendix A for detailed Bill of Quantities)

3.3.3 The Tasks

The programme of experiments therefore involved teams of two people, each team being assigned two tasks. Task 1 is undertaken using FTF collaboration and consists of 4 worksets (i.e. sectors): the exterior walls, the floor of the building, the roof of the building and the electrical work. Task 2 is undertaken using CMC collaboration and also consists of 4 worksets: the interior walls, the furniture, mechanical equipment and plumbing fixtures, the architectural design and site as well as the exterior walls and stairs. The details of the tasks, as given to the users are in Appendix B and the users are also told the contents of worksets. The task in FTF was necessary different to that in CMC, so that a team running the experiment a second time (whether in FTF or in CMC) would not know the answers already. However, the task in FTF and CMC were designed to be similar in difficult and in their use of Revit. While both FTF and CMC tasks were set up in Revit, since both users accessed Revit via the same PC in FTF, the arrangement of the tasks in different worksets was not particularly apparent nor relevant. However, in CMC, ownership of the worksets was distributed between the two users, and hence the users had to additionally ask each other for access to worksets. The order in which the users undertake the tasks (i.e. FTF and CMC) is random to avoid any systematic bias in the results. Furthermore, exactly half of the experiments were conduction with FTF before CMC. All users were asked to comment on the level of the task difficulty and task similarity in both FTF and CMC after their experiments and 90% of the users said that the difficulty of the two tasks was the same i.e. the two tasks were equivalent and comparable. For both the FTF and CMC tasks, the users have to work using the 3D computer model of the building. The model is deliberately deficient and hence has to be modified, so this is a task which involves a relatively mature design rather than conceptual design. The latter has been studied in the work of Alel et al. (2010), who have used conceptual design type tasks to test the effectiveness of CMC compared to FTF.

At the start of each task, the users were given instructions of the individual tasks to be performed on a sheet of paper. For each of the two users within a team, the tasks were different so, within each experiment, every user had a different set of instructions (see Appendix B). The instructions were carefully devised so that the tasks could not be carried out without assistance from the other user. This approach enforces the need for collaboration and hence communication. Great care was taken before the experiments to ensure that the users were given identical verbal and written instructions and that the users were not told anything about the purpose of the experiments. Likewise, they were instructed not to discuss what had occurred with anybody else when the experiments were over to avoid "contamination" of potential future users.

The tasks for each workset are arranged in a manner which controls and restricts the discussion. This was done to so that each time the experiment is run, the subjects considered by the users are similar and therefore comparable and also to keep the time for each experiment within reasonable bounds. The users are asked to look at various aspects of the building and where they think it is appropriate to amend the design. How and what to amend is left open to the users. Also, for the CMC experiments, the ownership of various sections of the building model is distributed between the two users so they are forced to collaborate to complete the tasks.

3.3.4 Hardware and Software

The system in this research is the Central Model or Client/Server which consists of two main parts: hardware and software. They provide an environment which is able to support the required tasks. Here, the hardware consists of one main computer (the server), which can be defined as computer which uses a specified software in order to serve and work with other computers (i.e. clients) (Amiri, 2002).

This server is located in the administrator's room and is associated with the two computers used for CMC which are located in different rooms. This system is able to support collaborative work between team members in CMC (i.e. system' users). All the team members work is based on a single file, named a central file, which is stored on the server. Each user downloads a copy of the central file on to their computer, this being identified as a local file. Each user is free to work on his/her local file and save it to the central file as shown in Fig. 3.2. The administrator monitors the collaboration process during the experiment through CCTV and also has permission to access the central file to see all the changes made by the users after the end of the experiment.

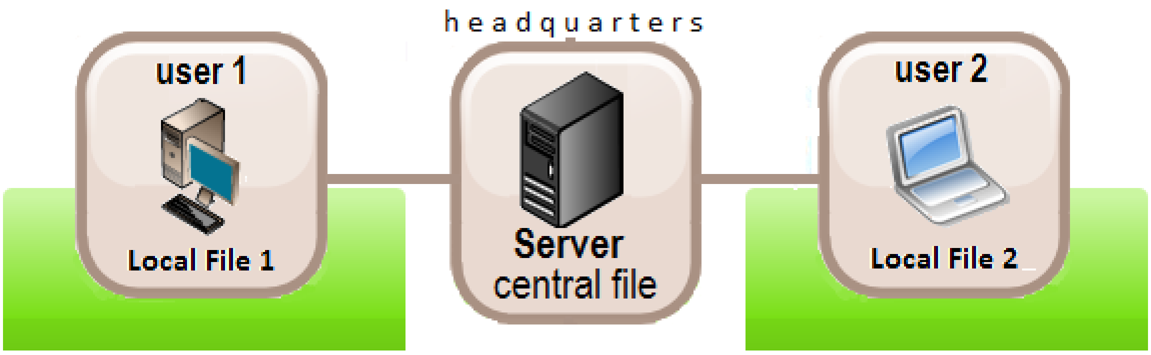


Figure 3.2: Hardware

The collaboration software used is Autodesk Revit Architecture, which is characterised as general design software not specific to any one particular sector in construction industry, unlike, e.g. Autodesk Revit Structure (only for structural designs) or Autodesk Revit MEP (only for the mechanical, electrical and plumbing sectors). Consequently, various specialists are able to use it, such as civil engineers, architecture engineers, mechanical engineers, quantity surveyors, etc. The model used in this research, as stated above, is that of a small simple house that requires work from various disciplines: civil, architectural, electrical and mechanical, etc. Hence, this software is suitable for this model (Section 3.5 provides further details about Revit Architecture).

3.4 Procedure for Experiments

This section details the design of the experiments, the experimental procedure, the recording of the results and extracting the required information in part using a coding system. Finally, the methods used for the analysis are described.

3.4.1 Experiments Details

The fundamental objective in conducting these experiments was to investigate the differences between people's behaviour and outputs from collaborative design, when it is conducted using FTF and CMC. Experiments were set up to explicitly examine this difference. Each experiment involves two users who are required to undertake a series of tasks relating to an existing Revit Architecture model of a building. The users have certain different tasks to perform for each communication method (i.e. FTF and CMC). Here, each task is discussed from different points of view since the building design contains some deliberate flaws and inadequacies and the users are asked to address and improve specific aspects of the building. The experiments for FTF and CMC have necessarily to allow for the different forms of collaboration:-

1- Face-to-Face (FTF): - The FTF experiments were arranged so that the users were physically together, sharing a single computer which they used to modify the 3D model. The actual sitting situation (i.e. directly facing each other or side-by-side) depends on the task type. For example in a competing task people sit side-by-side while for negotiations or meetings to discuss problems they sit in opposite each other (Wang and Hue, 2007). The arrangement of the seating positions around the computer was chosen by the users themselves, who had complete freedom in that choice (see Fig. 3.3).

2-Computer-mediated communication (CMC):- For the CMC experiments, the users sat in different rooms and worked on a single Revit model which is situated on the server (see Fig. 3.4). Each user needs to check out a copy of this central file and thus works on the local copy of the file, which then has to be saved back to the central file as shown in Fig. 3.2. This additional process (which is not found in FTF) is a fundamental integral component of the CMC setup, and thus its impact is inextricably bundled within the CMC package, and hence the comparison of FTF to CMC results have to be understood to be not only about comparing the communication method, but the overall processes involved in the two communication methods. For the CMC experiments, the communication between the users was achieved using Skype for both audio and visual purposes, the latter consisting of a small image of the other user on the top left of the screen. At no time do users share a desktop, hence all the communication concerning the task has to be verbal or through the chat facility in Skype.

Figure 3.3: An FTF experiment

Figure 3.4: An CMC experiment

The user who is designated as User1 in FTF (i.e. the user who principally controlled the mouse was a matter to be settled between the two users themselves) remains the designated User1 in CMC, and the computer used in FTF became the computer for User1 in CMC, i.e. it turned out that it was always User2 who moved to a new room. Which user has to move could have been randomised, but since the equipment set-up is the same in both rooms, it was felt to be better to minimise the possibility of confusion and error arising from mixing up User1 with User2 in the analysis.

3.4.2 Recording the Experiments

The experiments in FTF and CMC were recorded in order to collect the information on the interaction between the users' behaviour and actions.

In FTF, the experiment recording process involved two aspects as follows:-

1. A video camera was used to record the interaction between the users and create an MWV file (see the left hand side of Fig. 3.5).
2. The changes to the model made by the users were recorded using Camtasia Studo3 software (i.e. a screen recorder) to obtain a video clip file (AVI) (see the right hand side of Fig. 3.5). The two files were subsequently merged using Corel Video Studio 12 software to make the analysis process function more efficiently (Fig. 3.5).

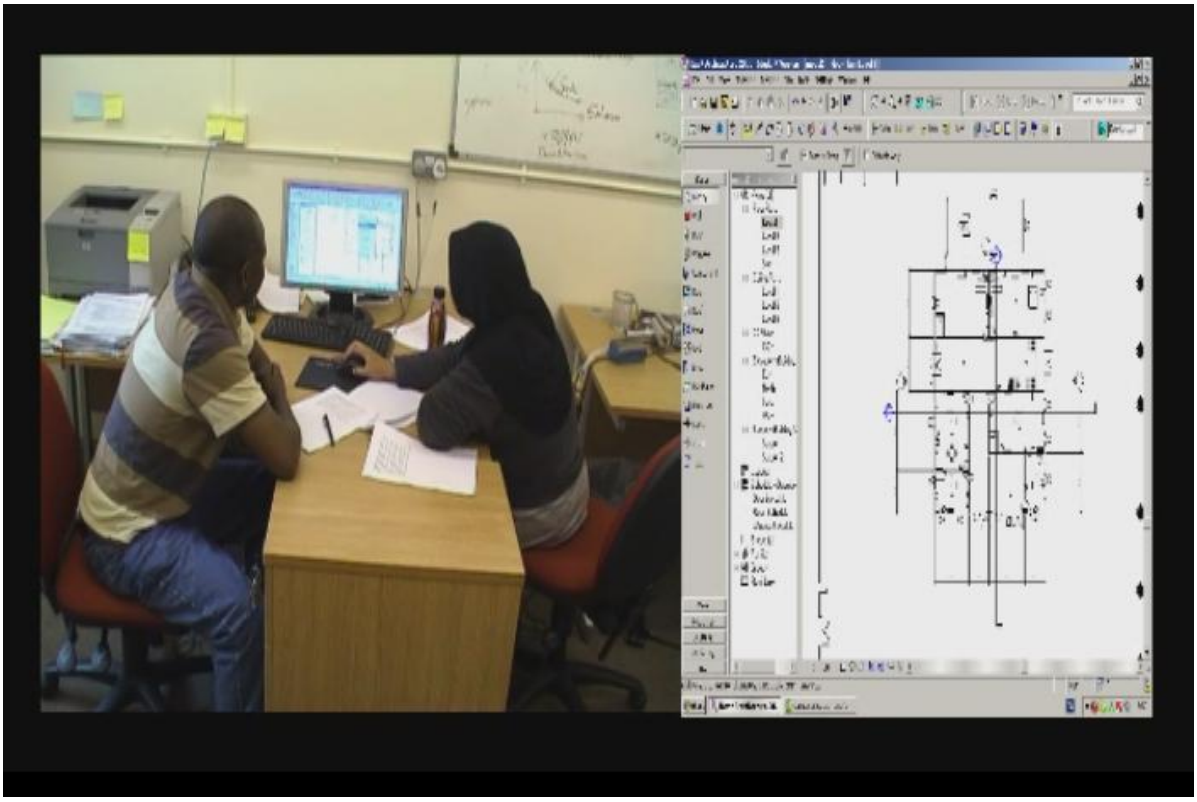


Figure 3.5: Merged files in FTF

For CMC, the recording of the experiments was divided into two parts.

1. The changes made by each user were recorded separately using Camtasia Studo3 to produce two AVI files (one for each user) (Fig. 3.6).
2. The two users' movements and actions were monitored and recorded by CCTV cameras to obtain a further AVI file (see the top of the Fig. 3.6).

The three files were merged into one using Corel Video Studio 12 as shown in Fig. 3.6.

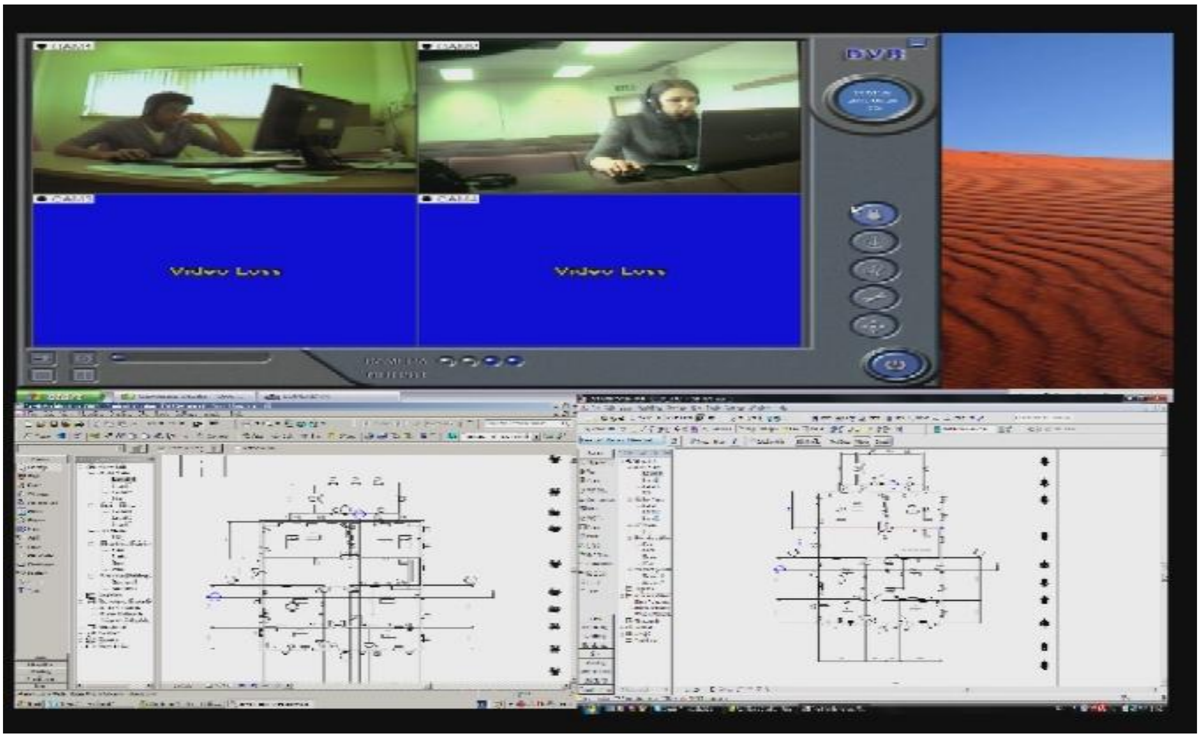


Figure 3.6: Merged files in CMC

3.4.3 The Transcription Extract and Coding System

As described above, a full audio-visual recording of each experiment was produced. The audio component was then transcribed. The details of the transcription were analysed and classified using a set of criteria which were developed as a part of this research. A feature of this work is that the majority of the users are not native to the UK, and therefore many did not speak English as a first language. Nonetheless, even when two users shared a different first language, all the communication in the experiments was conducted in English, and therefore no translation was carried out in the transcription. This feature ensures that the words in the transcripts are those of the users and have not been interpreted by the researcher. Table 3.2 provides an example of a short extract of transcript.

In order to make the analysis of the transcription easier, each statement by a user was tagged with a coding system, as shown in Table 3.3. The coding system has been specifically developed for this work and it seeks to record the nature of the conversation in the transcription extract. It then used to help with the analysis of transcription. It consists

Table 3.2: Transcription extract

Speaker Turn	**Time (Sec)**	**Line number**	**Speech**	**Comments**
User1	4	1	[[hello how are you, are you fine]]	Non work related words
User2	8	2	[[hello thank you {ssss} I am ok]]	Non work related words
User1	15	3 4 5	We will discuss of them step by step and we Change **during our progress look at the** **computer**	User2 agree and say yes {H.N}
User2	10	6 7	*{Exterior wall discussion can be divided for* *many divisions}*	User2{E.Y.C} to User1
User1	4	8	What is this?	User2 emphasizing
User2	12	9	But this is block and this is brick what is your opinion	User2{Int} User1
User1	10	10	Let us discuss each one individually You said the brick(48) cm.	User1{TT}
User2	7	11	I think that is funny idea is it!	User2{RR}
User1	10	12	This window or{ssss) ok ok	User1{WW}

Table 3.3: Coding system

Code	Meaning	Code	Meaning
{ssss}	Slight pause during the conversation	**{***That is bad idea***}**	Speech in soft words
{That is good idea}	Words in emphatically	**{RR}**	The user was relaxed
{E.Y.C}	Eye contact for the speaker	**{EM}**	The user was embarrassed
{That is great}	The user is smiling or laughing	**[[hello how are you, you are fine]]**	Non-work related words
{H.N}	Showing agreement by a head nod	**{Cof}**	The user was confident
{yes……but ..ok}	The user was worried {WW}.	**{Int}**	One user interrupts the other
{EE}	The user was emphasizing a point during the discussion	**{TT}**	The user was tense

of two parts. The first part is a textual transcription of the speech, with additional typeface coding to indicate the tone, e.g. emphatically spoken words are transcribed in bold, italicised text means softly spoken words, words between big brackets means non-work related words, and so on. The second part catalogues the observed condition of the user during the experiment with insertion of coding "symbols", e.g. {RR} represents the user was relaxed, {EM} means the user was embarrassed, and so on. Although the coding system was useful, the original audio-video recording was also extensively played-back alongside the coding in the analysis.

The next stage, after transcribing all the words uttered by each user was to extract the data for the following three categories:-

- The total number of words
- The number of work related words
- The number of non-work related words

Additionally, the usage of the allocated time during the experiment was analysed for each team and for each user according to three types:-

- Working time

- Wasted time
- Non-specific time

Finally, the number of exchanges (defined as the number of times the discussion moved from one user to the other during the experiment) was also recorded.

Appendix C explains pattern the details that were computed from the analysis of each experiment.

3.4.4 Analysis of the Results

An analysis of the results was undertaken by extracting from the transcripts of each experiment the above mentioned data. Most of these measures were calculated for each individual and then aggregated, where appropriate to obtain the team performance. To demonstrate the difference in the users' behaviour during FTF and CMC, twenty experiments were conducted using twenty teams, each team consisting of two users. The teams were told they had 35 minutes to complete a task, and they were instructed to cease work at the end of their allotted time.

For the analysis, each experiment was divided into seven intervals, each of five minutes. Other time intervals were also examined, but the five-minute interval was found to be the best size, on balance, between a sampling interval being too big (leading to fewer data points and the overall pattern being obscured) and a sampling interval being too small (leading to data points collecting insufficient information for them to actually display the overall evolving pattern). The results of each experiment were fully studied and analysed and the average (over 20 experiments) of each aspect was computed to allow the comparison of the differences between FTF and CMC. The analysis allows the comparison of the performances of individuals for each type of experiment, plus a comparison of how each pair performed in comparison to the other teams. Since the users had varying levels of expertise from expert to novice, the results allow inferences to be drawn about how the various teams perform. All the different parameters assessed for comparison have been found in the literature review and hence their use here follows commonly accepted methodology. However, on the aspect of assessment of design quality, no standard commonly accepted parameter or metric was found to be suitable for this work, and hence a bespoke evaluation form has been used for this research. The performance comparison includes:

- The number of words for each team and each user, this being an indication of the level of communication and also establishing if one team member is more dominant. Similarly, the number of non-work related words provides an indication of how effective and task focused the users were.
- The productivity of each team and individual productivity regarding the completion of various items. Additionally, the productivity of single users was calculated for different types of users according to their expertise level and compared with the team productivity to establish the differences in productivity.
- The time spent on the task and the non-task time (i.e. non-productive time) for each team user.
- The total number of exchanges (percentage of interactions) between the users is an indicator of the degree of collaboration with others indicators such as the percentage difference in individual productivity, the percentage difference in the total number words spoken by each user, and the percentage difference in the task working time between the users also being consider.
- The quality of each team's solution for FTF and CMC gives an indication of which method is better in this aspect. To determine the design quality for each team, a special form was prepared to assess the efficiency of the design quality by observing the decision making by a team for any item while carrying out the task, as shown in Appendix D. This form in FTF and CMC consists of four items, each item being divided into two parts. The first part relates to the fundamental requirements which satisfies the basic design requirements; this part scores from 6 (extremely correct) to 1(not at all). The second part is identified as the usability requirements, which is related to the material type and specification, and according to the form, has a score from 4 (extremely correct) to 1 (not at all). Generally, if a team works according to the best design quality, it will receive 10 points out 10 in each item.
- An analysis of the behaviour profile for each user was undertaken to show the impact of emotional factors on individual productivity. Aspects of human behaviour reflect the individual's emotions which can have an influence on their ability to work effectively. These include symptoms such as postures, gestures, eye

contact and facial expressions. In this work, these are placed into one of three categories: positive, neutral and negative emotions. Here, emotions were classified into the three categories according to the behaviour of the users during the experiment. Each category is assessed using a number of factors to measure the behaviour of the user and is aggregated and processed to give a score from 5(extremely) to 1(not at all) for each type of emotion (i.e. positive, neutral and negative) as shown in Appendix E. In this way the behaviour profile for each user can be obtained.

- Studying and measuring the non-verbal communication components such as body movements which include facial expression, eye contact and changing voice tone and cataloguing them for both users according to the five main elements illustrations, regulations, adaptors, emblems and affect display movements in FTF . Additionally, establish the relationships between the teams' productivity with NVC movements. Here, it is necessary to record all the body movements of the users during the experiments. This has been done using an observation form as shown in Appendix F. This form is used to analyse the video camera recording, so that all the information details concerning the body language for each user in the experiments could be obtained.

3.4.5 Statistical Analysis of the Results

There are two types of statistical analysis used in the research, the first one was Spearman's Rank Correlation Factor which has been used in this research and is applied every time to measure the degree of dependency between two sets of data, while normalising the effect of units. There are several relevant advantages with method which works with the ranking of the data: it can be used with a small sample size; it is easy to apply; it is relatively insensitive to outliers; and the data can be collected over irregularly spaced intervals (Gauthier, 2001). The last two advantages are particularly relevant in the current work. A correlation factor of +1 denotes a perfectly monotonic increasing relationship between the two variables, -1 denotes a perfect negative relationship, while 0 denotes no relation between the two variables (Storch and Francis, 1999).

Many researches apply a subjective description according to the strength of the correlation factor between the two variables (see Table 3.4). It is clear that there is some variability in the semantic range applied in the literature. In this research, the correlation factors are defined as :< 0.60 is termed “weak”; those from 0.6 to 0.79 are considered “moderate”, those from 0.80 to 0.89 are “strong” and those ≥ 0.9 are considered “very strong correlations”. In addition to the correlation factor, it is also useful to find the slope of the best-fit straight line to show how strongly is one variable dependent on the other.

Table 3.4: Correlation scales classification according previous researchers

Author	Correlation Scales						
Dancey and Reidy’s (2004)	**No-association**		**Weak**	**Moderate**	**Strong**		**Perfect**
	0.00		0.10-0.39	0.40-0.69	0.70-0.90		1.00
Kelly et al.,(2003)	0.00		0.20-0.49	0.50-0.79	0.80-0.90		1.00
Dyer (2006)	**Zero**	**Very Low**	**Low**	**Moderate**	**High**	**Very high**	**Perfect**
	Random relation	0.10-0.29	0.30-0.49	0.50-0.69	0.70-0.89	0.90-0.99	1.00

The second type of statistical analysis used in this research was the t-test. This technique is used to find the difference between the means of two independent samples and examines whether this difference is considered statistically significant or not (Pyrczak, 2002). This statistical test is widely known and used because it has many advantages such as being simple; easy to use; applicable in many situations and capable of being applied to a relatively small sample size (Cochran & Gertrude, 1992). This last advantage is particularly relevant in the current work.

The t-test provides a measure of the significance in the difference between the means of two sets of numbers, e.g. set A and set B (e.g., David, 2000). The t-test points to "statistical significant" when the "t-value" is greater than the "t-critical" value where:

t-value = $(M_A - M_B) / (\text{est. } \sigma_{M-M})$

and $(M_A - M_B)$ is the differences between the two means;

$(\text{est. } \sigma_{M-M})$ is the standard deviation of the sampling distribution of sample-mean differences and is calculated as

$$\mathbf{st.}\,\sigma_{M\_M} = \text{sqrt}\left[\frac{\{S_p^2\}}{N_A} + \frac{\{S_p^2\}}{N_B}\right]$$

$\mathbf{S_p^2} = \frac{SS_A + SS_B}{(N_A - 1) + (N_B - 1)}$ is the variance of the two samples

$\mathbf{SS} = \sum (X_i — M_X)^2$ is the summation of the squared deviates for each set, (X_i) is the values of each point in the set,

(M_X) is the mean of each set.

"t-critical" value is obtained from tables using the "degree of freedom" and the "alpha level" which represents the probability of random errors in the results,

and degree of freedom, **df** = $(N_A - 1) + (N_B - 1)$ where N_A and N_B are the sizes of sets A and B respectively.

3.5 Collaboration Software

Developments in software for facilitating construction industry design have resulted in a radical transformation from the old traditional 2D CAD methods to the modern 3D CAD and associated methods such as Building Information Models (BIM) (see Section 2.3.3). The greater efficiency of this software is leading to its increasing adoption by many organizations and companies in the industry.

The software used in this research to support collaborative working for both FTF and CMC is Autodesk Revit Architecture 2009 which is an Autodesk product and it is based on a 3D building information model (Autodesk Revit Architecture, 2010). Revit Architecture is one of several forms of commercially available software with similar capabilities and which is used by numerous organisations and firms. It can be used as design tool in the early phases of a project's lifecycle and then as the design progresses, further detail can be included so that it is relevant to all later stages of the design and construction process. Revit was designed as a BIM platform to meet the needs of the architecture, engineering and construction (AEC) industry. An additional feature of Revit is that it includes communication, collaboration and change management, and additionally supports structural, mechanical, electrical and other disciplines during design stage (Dzambazova at el, 2010). One of the benefits of this software is that it can supply full details for each element in the design in order to provide the user with all the details during the selection of the alternatives. The complete model where both geometrical and other data for every element are specified is known as a Building Information Model (BIM) (Autodesk Revit Architecture, 2010).

Revit has no inbuilt method for communication and hence Skype has been used in this work for users to communicate with each other. This is one of the deficiencies of Revit Architecture (2009) which is not as good at supporting collaboration between team members as other software, such as Adobe Connect which gives good level of collaboration. However, Adobe Connect is designed for large scale corporate collaboration over central Adobe servers, and so it was prohibitively expensive. On the other hand, Skype was free and yet found to be more than adequate for the purpose of a small team, and it was thus adopted. The following is a brief explanation of the features of Revit Architecture.

3.5.1 Revit Architecture Features

Revit contains many features that allow people to work simultaneously on the same model but not on the same parts of the model (Dzambazova at el, 2010). The responsibility for modification, and the authority to modify, the various worksets in the model, for example, the exterior walls, roof, plumbing, etc., are typically allocated to different people. In the present work which involves only two users, if someone wishes to modify something which impinges on an object which they do not own, then they have to request permission from the other user to do so. The tasks in this research have been set up so that the work necessarily involves such requests. The model which the users are required to work on is deliberately sub-standard so that the need for modification is relatively obvious.

There is a misconception which is prevalent in the construction industry of the usage of BIMs and their impact on productivity. A study conducted by Lott Barber Architectures (as reported by Rundell, 2007) used two types of software for two projects which were similar in size and scope. Although the data collection methodology is not actually clear, comparison between the time spent on different stages in the design process led the authors to conclude that the use of Revit was more economical than the traditional CAD tools, as shown in Table 3.5 (Rundell, 2007; Kumar and Mukherjee, 2009). One of the main reasons for this is that with traditional CAD, the user must carry out a considerable amount of manual updating while Revit is able to deduce the implications when the changes have occurred and completes the entire series of change updates automatically without any effort from the user. Additionally, Revit helps to prevent clashes and conflicts between the users during collaboration work and this is a useful and important feature (Dzambazova at el, 2010).

Table 3.5: The differences in the time spent between the two forms of software (data as reported by Rundel, 2007)

Task	CAD (hours)	BIM (hours)	Hours saved	Time saving
Schematic design	190	90	100	53%
Designing development	436	220	216	50%
Construction documents	1023	815	208	20%
Checking and coordination	175	16	159	91%
Total	**1824**	**1141**	**683**	38%

There are many specifications for Revit Architecture that makes it more suitable and it enables users to learn about all the material specifications when using building information materials. Below are some of these characteristics related to the work in this research:-

- Revit's main objective is to facilitate the formation of BIMs; many companies have begun to adopt this system. In some states such as Finland, Denmark, Norway and USA, the use of the BIM has been endorsed (Arayici et al., 2009); while some other states have progressed toward it. Holzer (2007) stated that in USA, BIM use was also made compulsory to large extent, since the government agency General Service Administration in 2007 initiated a requirement for planners to use BIM as an open standard if they are applying funding for their projects.
- It shows all the elements as families, such doors, walls, windows, furniture, etc; in this way, the users can easily select the best solution from different alternatives.
- It can show the object in a textual manner.

- It can schedule all the components in the model using tables and links these components by a relationship. For example if the user changes the type of the windows in the tables, the windows will be changed in the model, and vice versa.

3.5.2 Project Collaboration

Many of software companies have focused on worksharing or supporting working as a team as desirable features to be incorporated into their products. This is due to the importance of this subject and the use of this form of working, especially in the construction industry where many companies are involved in a typical scheme and the tendency of these companies to be geographically remote from one another. Software companies vie with each other to develop and produce the best tools and facilities to make the application of the worksharing easier to use and learn. Revit Architecture is one of numerous form of software designed for this purpose with the provision of advanced tools to provide opportunities for collaborative work. Below is an outline for supporting collaboration using Revit.

3.5.2.1 Worksharing Terminology

First some of the important terms in Revit Architecture need to be explained:-

- Worksharing: - A design or implementation method which enables the team members to work together on the same project at the same time.
- Central file: - Sometimes called a “master project”:- this is a central file that stores all the current information of the project’s components and publishes all the information about changes during the work. Each user downloads a copy of the central file on to his/her computer. This is known as a local copy, and all the changes in these local copies will be saved in the central file. Additionally, all the users can see the changes that have occurred in the central file.
- Workset: - This is a classification or collection of project’ elements in the form of separate groups, for example, the doors, the windows, furniture, etc, to facilitate the distribution of work between project team members.

- Element borrowing: - This is a process used to allow the borrowing of elements from worksets owned by other users. If nobody owns the workset, permission can be obtained automatically, but if another user owns this workset, a request should be placed before obtaining permission. This is an essential rule for collaboration work in Revit Architecture (Wing, 2009).

3.5.2.2 Enabling Worksharing in Revit Architecture

There are a series of steps that must be followed when using Revit Architecture for collaboration. These steps are the foundation of the collaboration process using team work as follows.

1- Creating the central file: - When starting to create a central file from the existing model, this model is created by any user or by the administrator of the collaboration process; then the worksharing dialogue box shows the details of the shared level, grids and workset1, etc. The central file must have a specific name in order to be identified by all the users, for example, Cardiff University_CentralFile.rvt. In addition, this file must be saved in a network drive in order to allow all the team members to access this file easily.

2-Setting up worksets: - Only one user can work in each workset at any a given time. All the team members are able to see the worksets owned by the other users, but cannot change them.

3-Creating a workset: - The workset can be created according to the type of element, such as doors, windows or according to the size and the area of the project, e.g. the north building workset, the east building workset, or sometimes according to the level and floors of the building as shown in Fig. 3.7.

4-Adding Elements to a workset: - In order to add an element to any workset, the latter must first be activated by selecting from a workset toolbar. Then particular elements can be added or removed from the workset (Wing, 2009).

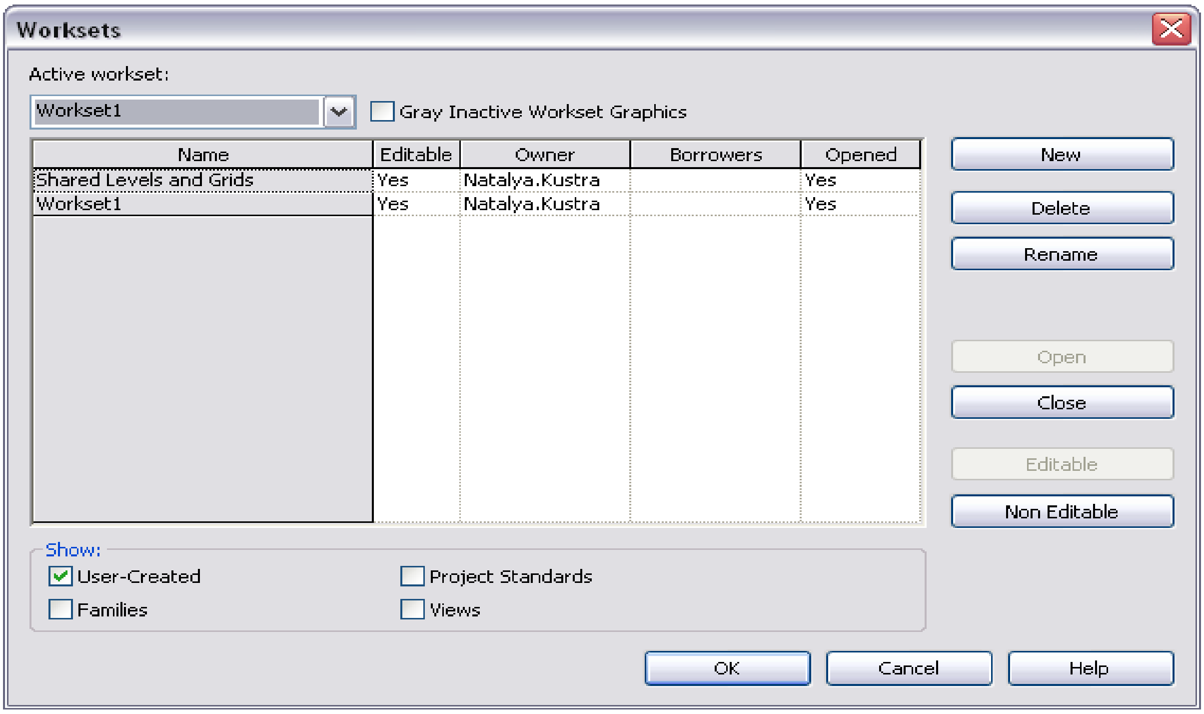


Figure 3.7: Create workset in Revit Architecture (Revit Architecture User's Guide, 2009)

5-Creating a local file:- Each user should have a copy of the central file in his computer according to the system architecture and this is called the local file.

6-Saving work shared files: - One of the most important factors that makes the collaboration work active and successful is preserving the information, and particularly establishing the updates of the users. Regularity in saving in both the local and central file is the best solution to maintain information. The optimum period for saving the local copy is 30 minutes and for the central file 120 minutes. The user can use this command to see the latest changes in the central file and can then update his or her local file accordingly (Revit Architecture User's Guide, 2009).

7-Borrowing Elements: - This procedure represents the core of the collaboration work. Here, partners talk and discuss using a specified tool provided by Revit.

There are two types of borrowing methods.

- Borrow elements from a workset which is not owned by anyone: Here, elements can be borrowed by clicking on the element to make it editable so that it can be used.

- Borrowing elements from worksets owned by other users: If an attempt is made to make the element editable (in the local file), a message displays to alert the user and inform him or her that "it is not possible to change the elements because another user is working on the workset". Here, there are two options: To place a request or to wait until another user relinquish the workset.

  Revit Architecture has a facility for checking the requests made by users by clicking "Editable Request". With a pending a request option, it is possible to check and see if a request has been accepted or refused (Revit Architecture User's Guide, 2009) as shown in Fig. 3.8.

Figure 3.8: The editing request list (Revit Architecture User's Guide, 2009)

3.6 Operating Software (Windows Server 2003)

In addition to the collaboration software, there is another software needed for operating this system which is Windows Server 2003. This software is one of products provided by Microsoft Company; it is useful, well supported and well proven software. This makes it important in many networks, particularly those where people depend on the use of the server in their work. Windows Server 2003 was chosen because it was available, known to work well and had technician support available within the School of Engineering. Additionally, benefits and features are:

- Dependable: - The software is fast and reliable, and helps to transmit and integrate information with a high degree of confidentiality and security.

- Productive:- The software contains tools and particular facilities to make the deployment and management of information faster and more effective
- Accessible:- The software produces an integrated web-server to help users connect easily and quickly with the best connection line (Hassell, 2006).

One of the main objectives of Windows server 2003 to save the shared data (i.e. database) in the central file; this file remains in the server in one place. All the users can access this file and manipulate its contents according to their contribution in the project.

3.7 Summary

In this chapter, a general introduction was given concerning the types of methodologies used in the research in general and the type of methodology which is used in this research. The chapter summarised the following points.

1. The experiment details in the two methods of FTF & CMC are explained, making clear the main requirements for conducting each method. It also established how the users were obtained, revealing that the categories were arranged according to experiences. Further to this, it showed how the transcript extract for each experiment was recorded.
2. Details are given about the methods of analysing the results, showing the important parameters to be measured, such as the total number of words of the team or individual productivity, team productivity, time divisions, team design quality, the behaviour profile for each user in the team as well as the non-verbal communication in the FTF approach and the effect of NVC movements on team productivity.
3. A study has been made of the system used and its details from hardware and software. Here it can be seen that Revit Architecture (collaboration software) was used during the experiments. Many details in Revit have been studied such as features, specifications, terms and work sharing terminology.
4. The chapter clarified the operating system was used to operate the hardware and establish its specifications and characteristics.

Chapter 4

Comparison between Face to Face and Computer Mediated Communication

4.1 Introduction

This chapter presents the basic results from the experiments involving either FTF or CMC collaborative working. As explained in the previous chapter the data have been gathered from 20 experiments for each form of collaboration with each pair of users participating in experiments involving both forms of collaboration.

The results are presented in a variety of ways, each of which has been chosen to extract and highlight the salient features of the forms of collaboration. Each experiment has been transcribed and from the transcript the interactions are broken down into discrete exchanges as explained in Section 3.4.4 of the methodology. A considerable degree of thought and effort has gone into determining which features are significant and what is the implication of the various results. This work has mainly focussed on determining the difference between the performances of the users when undertaking tasks FTF and using CMC. The chapter is divided into five sections, as follows:-

1. Section 4.2 studies the total number of words said during each experiment and the total number of words said by each user. This is then broken down further into the number of work related words, number of non-work related (i.e. social exchanges), number of word said emphatically by each user and the number of words said softly by each user.
2. Sections 4.3, 4.4 and 4.5 examines the time broken down into working time for each team and working time for each user, wasted time (i.e. time when the users were clearly doing non-work related activities) for each team and wasted time for each user and non-specific time (time when it was not possible to determine what the users were doing).
3. Section 4.6 considers the number of exchanges (i.e. number of times one person ceased speaking and the other started during the experiments).
4. Sections 4.7 and 4.8 studies team productivity for each method and the effect of emotional factors on team productivity. Finally a behaviour profile for each user in both FTF and CMC is presented.
5. Section 4.9 discusses speech rate for each user during the experiments which represents one of the indications of user behaviour.

4.2 Total Number of Words

The total number of words said during an experiment is a measure of the amount of communication that occurred. Obviously though, it does not give an indication of the quality of the communication. The following results are the averages for the 20 experiments. As shown in Fig. 4.1, the total number of words said by each team is higher in FTF than in CMC by about 19%. Over the seven 5-minute intervals, FTF on average recorded 331.3 words per 5-minutes while CMC recorded 277.9 words. This is a significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 6.62, which is greater than the corresponding t-critical value of 2.18 (or 4.32) with a degree of freedom of *df* =12, and a probability of error < 5% (or < 0.1%). The fact that FTF incurred more words than CMC could be attributed to a number of possible reasons but the analysis of the transcripts shows that for CMC there is a stronger focus on task related factors and less time spent on social aspects.

Figure 4.1 gives a plot of the average number of words spoken for all the experiments broken down into five minute intervals. It can been seen that for FTF and CMC, both curves follow similar trends with peaks between 5 and 10 minutes and a dip between 15 and 20 minutes, both presumably being related to the particular features of the tasks within the experiments. As can be seen throughout the experiments the total number of words in FTF is higher than in CMC.

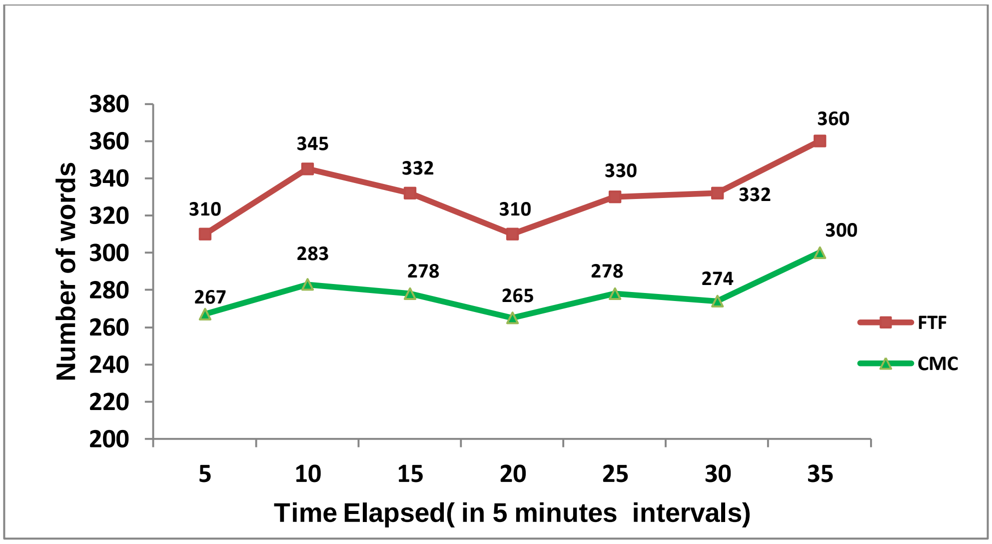


Figure 4.1: Total number of words in FTF and CMC

4.2.1 Total Words for User1 and User2 in FTF and CMC

Total number of words for the users is defined as words spoken by each user during each time interval. The results plotted against each time interval for FTF and CMC are shown in Figs. 4.2 and 4.3 respectively.

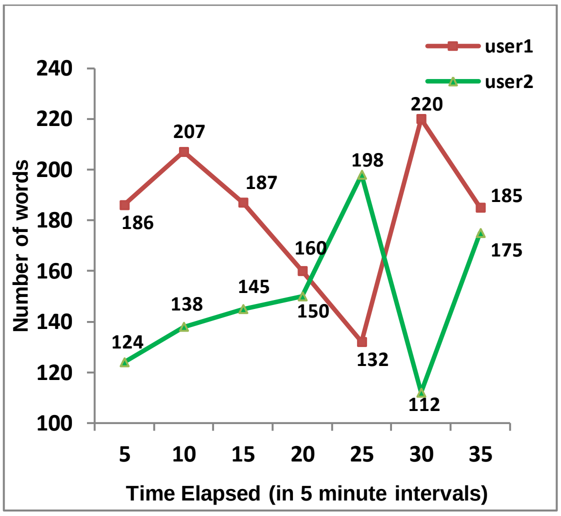


Figure 4.2: Total number of words said by users in FTF

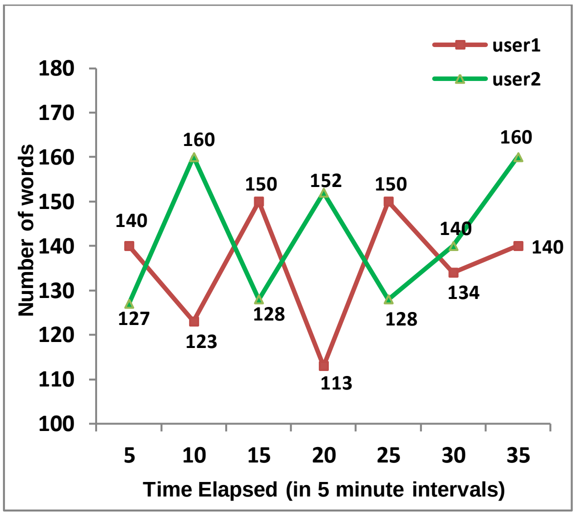


Figure 4.3: Total number of words said by users in CMC

Dealing with the FTF results first in Fig. 4.2, the total number of words said by User1 is higher than for User2 for all except the fifth time intervals. A more detailed observation of the video recording shows that correspondingly, User1 more often interrupted User2, or continued to speak over User2, and more insistently put forward his ideas on how to solve the problem, while neglected some of the suggestions made by User2. The higher number of words spoken by User1, together with the visual observations point to User1 displaying a domineering behaviour, which was especially during the initial stages. However, but as can be seen in Fig. 4.2, User2 gradually became more assertive and then in the later stages, once again User1 spoke more. The total average number of words spoken by User1 is 1277 and for User2 1042 words.

In CMC, the results presented in Fig. 4.3 show that User1 and User2 alternate with respect to who spoke the greatest number of words during a given time period. This pattern of behaviour tends to indicate that either User2 was more confident than in the FTF experiment or that User1 was less confident (possibly a combination of both factors). This change compared to the FTF results might be attributed to the fact that User2 is not in direct contact with User1, as occurred in FTF and this resulted in a leveling of the degree of contribution more freedom and helped him/her to participate more freely. This result is consistent with the findings of Rice & Markey (2009) who stated that the interaction between the participants in FTF was less than in CMC (see Section 2.8.2). Total average number of words said by User1 is 950 while User2 said 995. Note that these totals are lower than for FTF, possibly due to communication being more difficult than for FTF or that there is less need for social interaction and so this aspect of speech may be eliminated. To obtain a definitive answer for this, further work is needed.

To conclude, User2 spoke less than User1 in FTF which suggests that User2 was rather subdued during FTF but was more confident when using CMC. The less domineering behaviour of User2 in FTF may be influenced by many reasons such as different levels of expertise; differences in age and the effect of emotional factors (see Section 4.8). In CMC all these factors were attenuated and the gap between the two users was diminished, this finding is comparable to that in the work of Riordan & Kreuz (2010) who indicated that the team members in CMC were less affected by emotional factors than the members in FTF (see Section 2.8.2), so they became closer to each other from the work achievement point of view which eventually resulted in better productivity as will appear in the next sections.

4.2.2 Work Related Words

The above was a comparison of the total number of words and it is hypothesized that the higher number of words for FTF is possibly due to the need for more social interaction when people are collocated. This can be checked by analyzing the transcripts to determine the number of task related words, defined here as work related words. Again the results presented are averages for all the experiments expressed as words said during 5 minutes intervals. The percentage of work related words spoken in CMC is higher than that in FTF, being 96.2% in CMC and 91.5% in FTF. Over the seven 5-minute intervals, FTF recorded on average 303.3 words for every 5-minute while CMC recorded 267.4 words. This is a significant statistical difference between the two averages because the t-value of the “two-tailed test” from the analysis of the results is 4.63, this being greater than the corresponding t-critical value of 2.18 (or 4.32) with a degree of freedom of *df* =12, and a probability of error < 5% (or < 0.1%). As can been seen from Fig. 4.4, the trend of the curves for work related words is very similar to the curve for the total number of words.

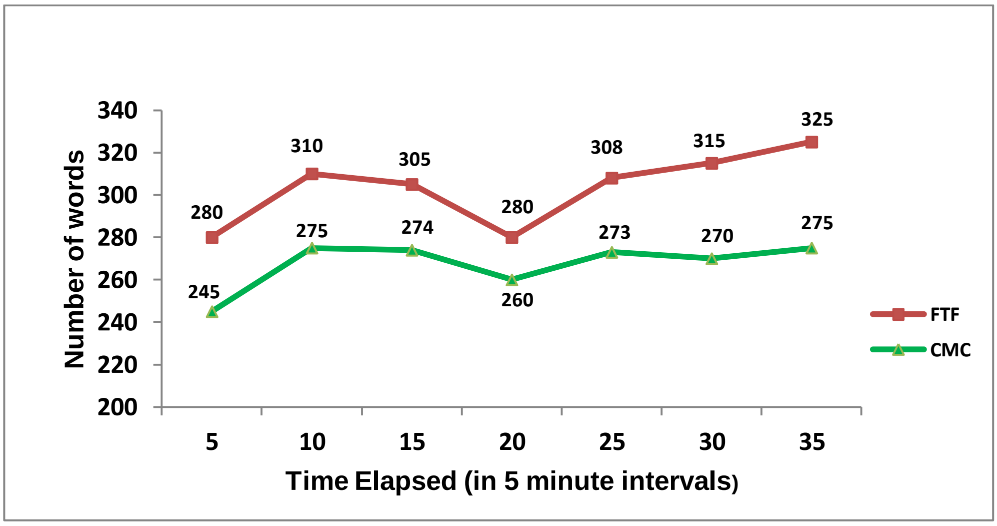


Figure 4.4: Total number of work related words in FTF and CMC

There are other possible explanations for the greater number of words spoken in FTF, for example the users could be looking more at options which should result in higher design quality. Conversely, the discussion might be non-productive, i.e. the users in FTF speak more because it is relatively easier to speak in FTF. Equally, the users in the CMC might be more focused on the task items because they each face a computer in front of them, and do not have the physical presence of someone near them to talk to. All of these are possibilities. The examination of productivity and design quality given later help to indicate which of these scenarios is more plausible.

4.2.3 Non-Work Related Words

From the above two Figs. 4.1 and 4.4, it is obvious that the number of non-work related words in relatively small but it is interesting to look at their distribution with time as shown in Fig. 4.5. Again the results are averages for all the experiments. The total number of non-work related words in FTF is 196 and in CMC 73 giving a percentage of the total words spoken of 3.8% in CMC and 8.5% in FTF. The average of non-work related words over the seven 5-minute intervals in FTF is 28 words every 5-minutes while 10.5 for CMC. This represents a significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 4.14, this being greater than the corresponding t-critical value of 2.18 with a degree of freedom of *df* =12, and a probability of error < 5%. As one would expect the total number of non-work related words in FTF is higher than in CMC for all time intervals, this finding agrees with the work of Kaushik et al. (2000) who revealed that the social presence in FTF is higher than in CMC (see Section 2.4.1).

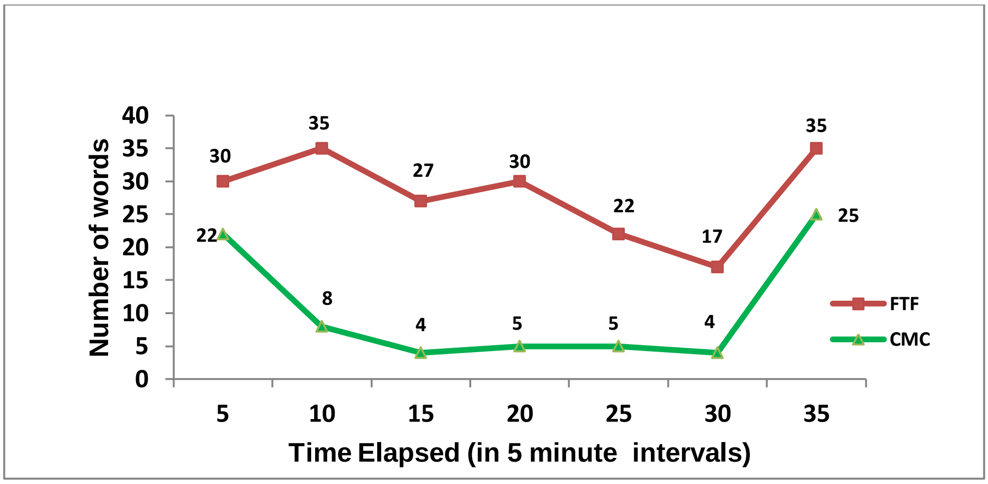


Figure 4.5: Total number of non-work related words in FTF and CMC

However the two curves exhibit distinct differences to those for work related words. With both there are a relatively high number of non-work related words at the start. This reflects a higher degree of social interaction, which is normal at the start of any interaction. The FTF curve has some minor intermediate peaks whereas the CMC follows a downward path until the last 5 minutes when there is a strong increase which is also present in the FTF curve. This again is social interaction as the end of the task is approached. An additional feature is that the total number of non-work related words is higher between users who already knew each other as compared to those who were strangers.

4.2.4 Words Said Emphatically

Another aspect of collaborative working is how things are expressed by each user. This can give an indication of stress level and dominance, features which potentially could change when people work using CMC rather than FTF. For these results, the presentation is again in terms of User1 and User2. The results are once again averages for all the experiments, and are presented in Figs. 4.6 and 4.7. A comparison between the two figures shows that there is a distinct difference between FTF and CMC with there being a much great degree of equality in the latter. It is assumed (but not proven) that this indicates that in the FTF, User1 exerted a high degree of dominance, especially in the early stages of the task whereas this appears not to be present for the CMC task.

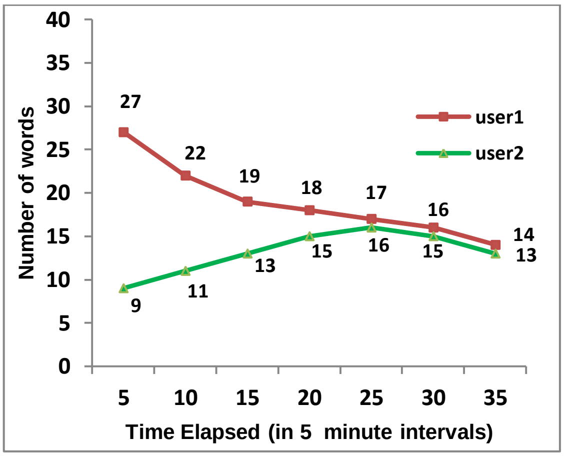


Figure 4.6: Total number of words said emphatically by users in FTF

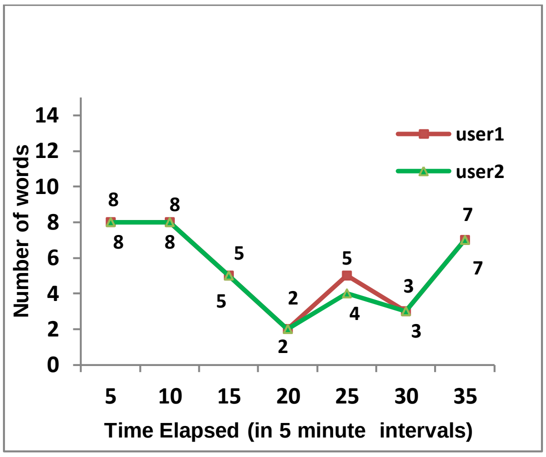


Figure 4.7: Total number of words said emphatically by users in CMC

4.2.5 Words Said Softly

In contrast to the results in the previous section, words spoken softly could be taken to imply a more submissive person, or some understanding of a more submissive role assigned to User2. Although there was no predefined User1 or User2, nor predefined roles for each person, nor pre-assignment of which member is User1 or User2, the emergence of User2 as typically the more submissive is most probably due to the (more submissive) nature of the person naturally taking on the (more submissive) position in the team. This submissiveness could be due to various factors such as emotional factor, experience or age. The results are presented in Figs. 4.8 and 4.9 and again are averages over all experiments. As can be seen, there are distinct differences between FTF and CMC, with User2 apparently being the more submissive in both experiments. However the total number of words is very small with User1 saying just 31 words while User2 said 61 words. Out of a total of around 2319 words per experiment, this is not a particularly significant feature but it has been included because it is consistent with the other results.

In CMC, both users said few words softly, it is noticed that both users said a lower number of words softly and emphatically in CMC as compared to FTF. User 1 didn't say any word softly in the first 4 time intervals while User2 said, and average of 4 words in each of the first 4 time intervals, during the last time intervals both users said almost similar number of words with an average of 1 word in each time interval. User1 said 7 words while User 2 said 24 words as an average as shown in Fig. 4.9.

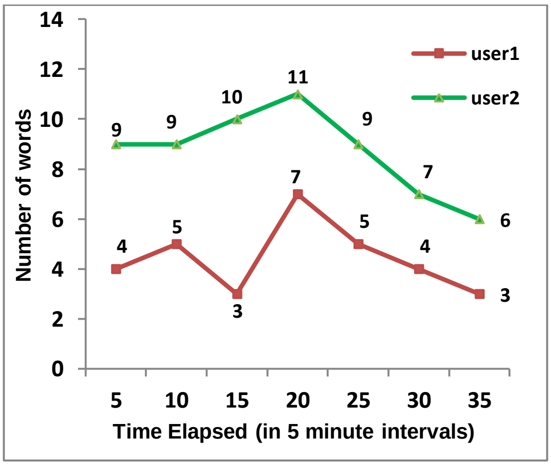


Figure 4.8: Total number of words said softly by users in FTF

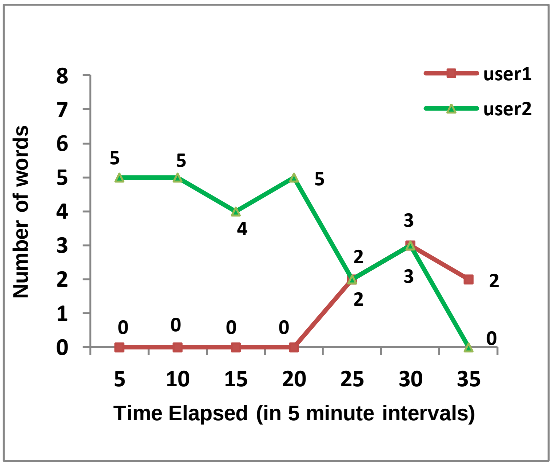


Figure 4.9: Total number of words said softly by users in CMC

4.3 Working Time

By observing the video recording and audio track of the experiments, it is possible to clearly work out when people were working productively, or were actually being non-productive (e.g. by idle chatting). However, when there is no obvious activity, it is impossible to be absolutely clear whether users are thinking about task related topics (i.e. working) or non-task related matters: this portion of the time has been set aside as "non-specific" time. Although later analysis of the activities and characteristics in the non-specific time would indicate that non-specific time is most likely to be non-working time, since such non-specific time may still include some periods of reflection, the three categories of time use have been retained, and "working time" consists only of the time periods where the observed activities are unquestionably productive. As with the above, the results are averages for all the experiments. Generally as is shown in Fig. 4.10, the working time for CMC is slightly higher than that for FTF. This can be interpreted as showing CMC is more productive than FTF or that more effort is required for CMC because of the additional load imposed by the limitations of the communications. Which of these explanations is more plausible will become clearer when further results are presented. As can be seen from Fig. 4.10, the distribution of work activity with time is very similar for FTF and CMC although the distribution is more even for CMC. Over the seven 5-minute intervals, the users in FTF spent an average working time of 249.3 seconds for every 5-minute while in CMC the users spent 256.6 second. This is a significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 2.4, which is greater than the corresponding t-critical value of 2.18 and has a degree of freedom of df =12, as well as a probability of error < 5%.

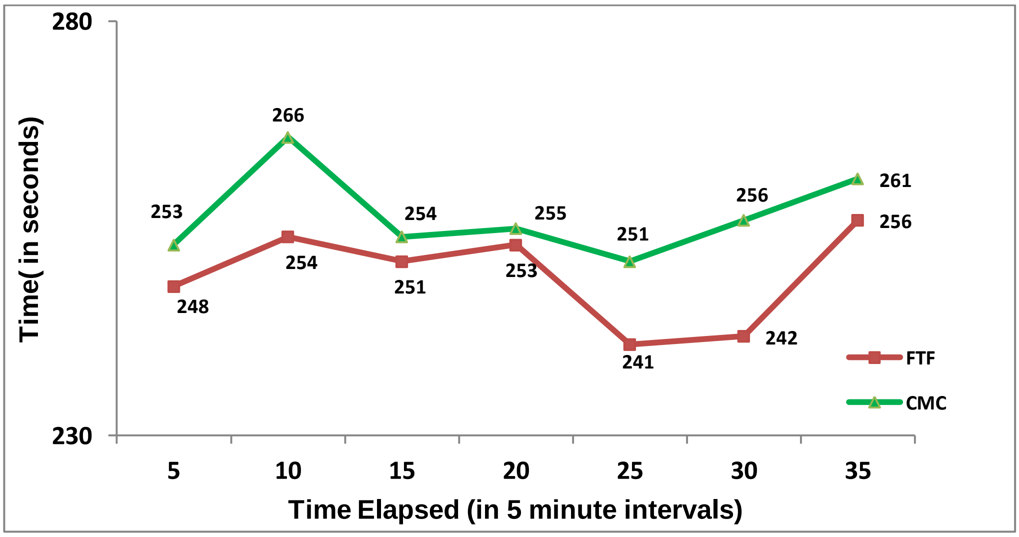


Figure 4.10: Total working time in FTF and CMC

It is also interesting to look at the distribution of working time for User1 and User2. The averages of all the experiments are presented in Figs. 4.11 and 4.12 with the former being for FTF and the latter for CMC. In FTF, during the first half of the experiment, it can be seen that User1 spent more working time than User2 while in the second half of the experiment the situation is different because the level of activity is much more equal. This is consistent with the results presented in Figs. 4.2 and 4.6 with User1 being dominant in the first part of the experiment but with a greater level of equality in the second part of the experiment. The averages of the totals are, for User1 968 seconds of working time, and for User2 777 seconds.

For the CMC results in Fig. 4.12, the pattern is distinctly different with a much greater level of equality and towards the end, User2 exhibiting more activity. This is consistent also with the results presented in Figs. 4.3 and 4.7. This strengthens the previous impression that CMC removes the ability of one user to dominate another and so could possibly be a good way of making the best of all available expertise rather than having one person dominating the decision making. The average totals for all experiments are, User2 923 seconds and User1 873 seconds.

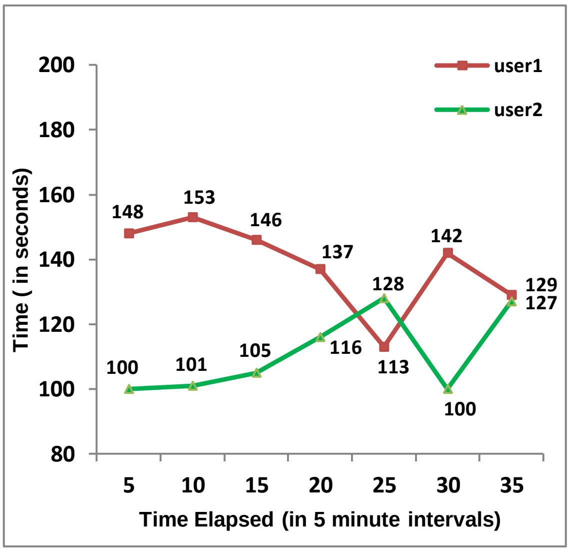


Figure 4.11: Total working time spent by users in FTF

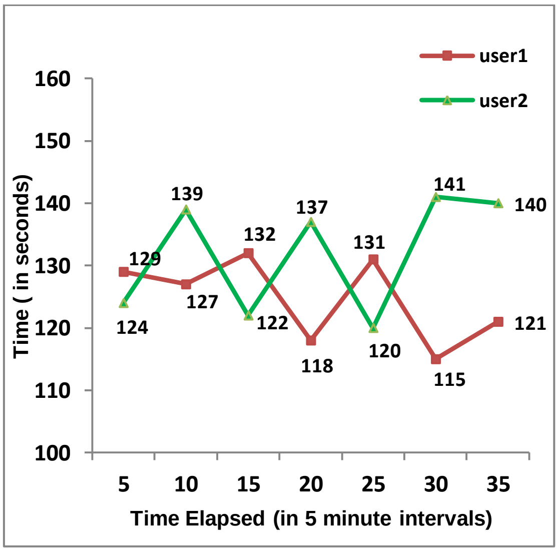


Figure 4.12: Total working time spent by users in CMC

4.4 Wasted Time

Wasted time is defined as the time which is spent uttering non-work related words and the duration of deliberate pauses during the experiment (e.g. checking email), this time can be extracted from analysing the video recording directly. The measure is not absolute because during pauses, users may be thinking. As can be seen from the results presented in Fig. 4.13, wasted time for FTF is consistently higher than wasted time in CMC. This indicates that CMC promotes a more task related use of the time. As stated above, this could be an indication that the users find CMC a more difficult way of working or that they feel there is less need for social interaction. The averages of wasted time spent in seconds for every 5 minutes in FTF are 38.71 and 27.71 for CMC. This can be considered a significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 4.2, this being greater than the corresponding t-critical value of 2.18 with a degree of freedom *df* =12, as well as a probability of error < 5%.

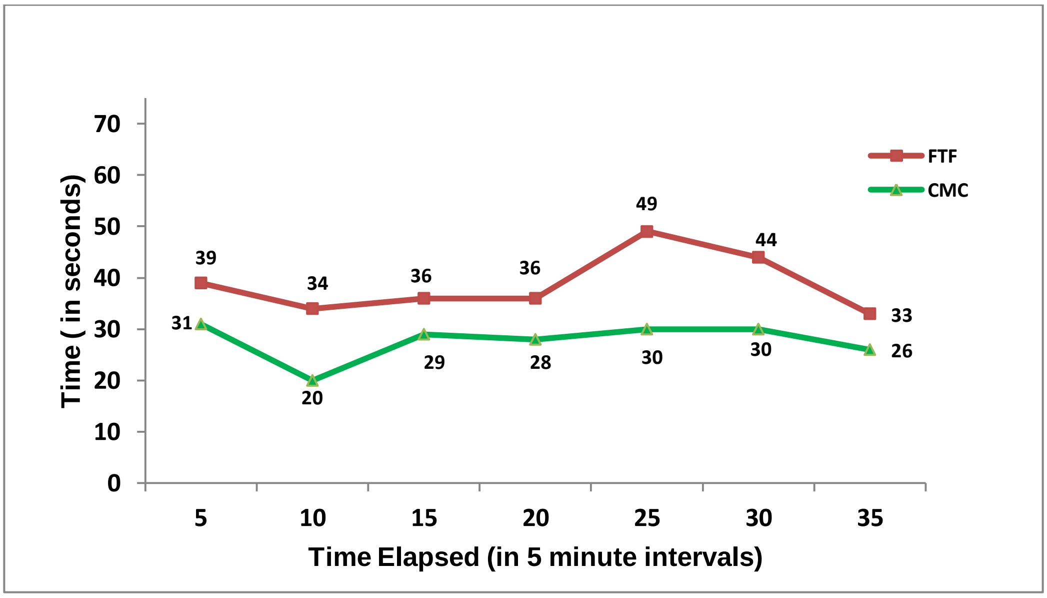


Figure 4.13: Total wasted time in FTF and CMC

Wasted time spent by users in FTF differs from CMC; this is because CMC is slightly better than FTF in utilizing the time to achieve the task within specified time as shown in the results above. It has been found useful to examine the distribution of this time between the two classes of users and what was the relation between this time and behaviour for each user during FTF and CMC. The averages of all the experiments are presented in Figs. 4.14 and 4.15. In FTF, it is obvious from Fig. 4.14 that User1 wasted more time than User2 in all of the time intervals except at 35 minutes where User2 was slightly higher. The average wasted time spent by User1 was 24.14 seconds with standard deviation 4.74 while for User2 was 14.57 seconds with standard deviation was 5.02. This is assumed to reflect the fact that, the User1 was dominant and speaking more than User2, especially for non work related words also which is the main source of wasted time.

Figure 4.15 shows the wasted time for CMC; it is clear that the wasted time spent by both users was high at the beginning of the experiment and then it declines at the10 minute interval and then later in the experiments it increases. The wasted time spent by both users was nearly equal; User1 spent 14.14 seconds with standard deviation 6.25 while User2 spent 13.57 seconds with standard deviation 5.68. Generally wasted time was lower in CMC with no significant differences between the two groups of users, which again is an indication of a more equal form of working time than in FTF.

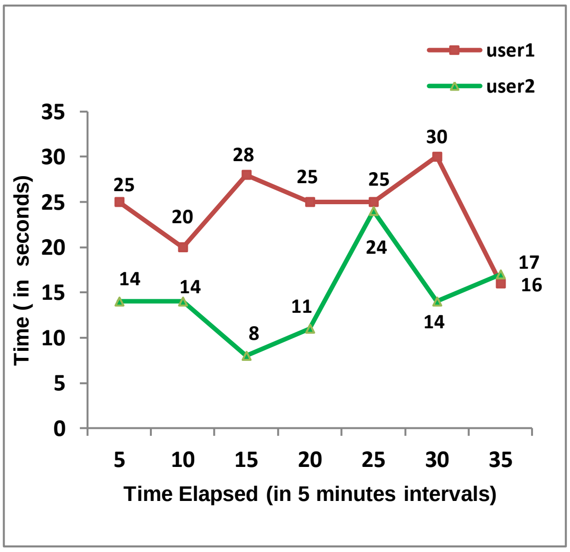


Figure 4.14: Total wasted time spent by users in FTF

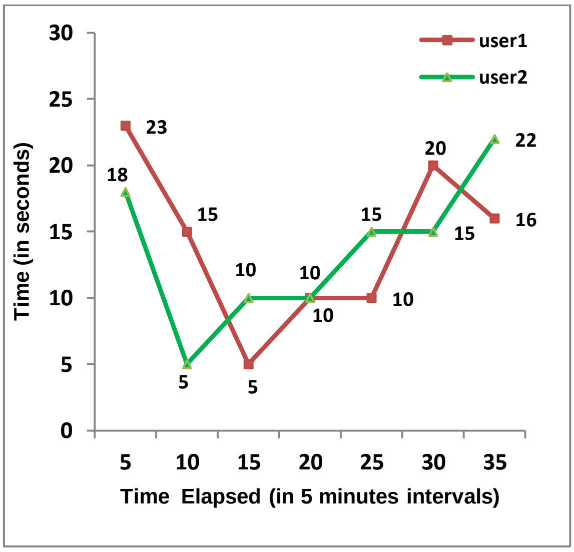


Figure 4.15: Total wasted time spent by users in CMC

4.5 Non-Specific Time

Non-specific time is defined as the time that cannot, on initial analysis of the video recordings, be clearly identified as either working or wasted, e.g. the user stops working or speaking, and instead glances around the room. Therefore in this and some of the following sections, its characteristics will be studied to see if its categorisation should be linked with working time or wasted time. However, analysis of the characteristics (especially productivity in next section) of the non-specific time can show it is better aligned with working-than wasted-time. If this time has taken the same trend of wasted time (i.e. reduce the productivity in each time interval) this means it is wasted. Conversely, if this time increases the productivity in each time interval this means working time.

As be seen in Fig. 4.16, non-specific time is consistently higher for CMC for all but one time interval. To try to get a better idea of what is happening in non-specific time (i.e. is it work related or not), the relationship between the general trend of the non-specific time and team productivity for each experiment has been investigated for each time interval. It can be concluded that non-specific time show the characteristics of working time and in 8 out of the 20 FTF experiments, and in remaining 12 experiments it is wasted time. For CMC, non specific time is equally split between wasted and working time, i.e. 10 of each. Generally non-specific time in FTF was 84 seconds per 35 minute experiment (i.e. very small amount); while in CMC it was 110 seconds. The averages of non-specific time spent in seconds for every 5 minutes in FTF are 12 and 15.71 for CMC. This shows a significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 3.83, which is greater than the corresponding t-critical value of 2.18 with a degree of freedom df =12, as well as a probability of error < 5%.

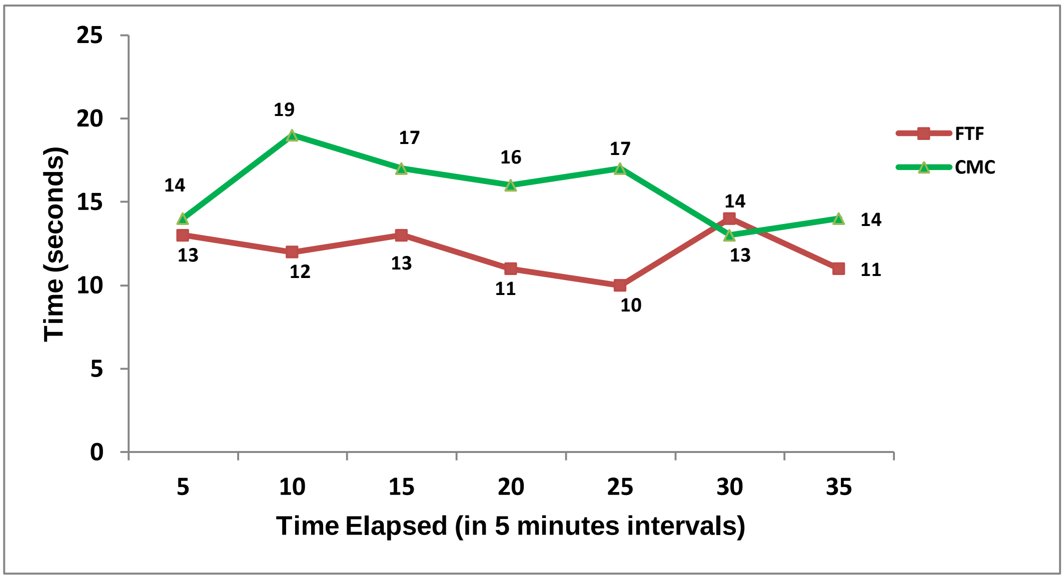


Figure 4.16: Total non-specific time in FTF and CMC

4.6 The Number of Exchanges

As defined above, the number of exchanges is the number of times which speech exchanges between users during the experiment (i.e. one person stops talking and other one takes over). As is shown in by Fig. 4.17, the total number of exchanges for CMC is higher than for FTF. The latter equals the number for CMC in the early stages but as the above results have demonstrated, this is where there is a higher degree of social interaction for FTF. When the users are more focused on the task then the number of exchanges is consistently higher for CMC, although as is shown by Fig. 4.17, the differences are relatively small. The average of the number exchanges between the users for every 5 minutes in FTF is 20.7 while for it is CMC 22.2. There is no significant statistical difference between the two averages because the t-value of the "two-tailed test" from the analysis of the results is 1.35, this being less than the corresponding t-critical value of 2.18 with a degree of freedom of $df = 12$, and a probability of error > 5%. However, one cannot say absolutely that this difference is due to a higher level of collaboration for CMC. It may be an indication of other factors but when one considers it in conjunction with the previous results, the balance of probability is that it is indicative of a slightly more collaborative way of working. This in itself interesting as one would intuitively expect that the barrier of not being FTF would be impedance, but the results presented so far tend to suggest that this is not the case.

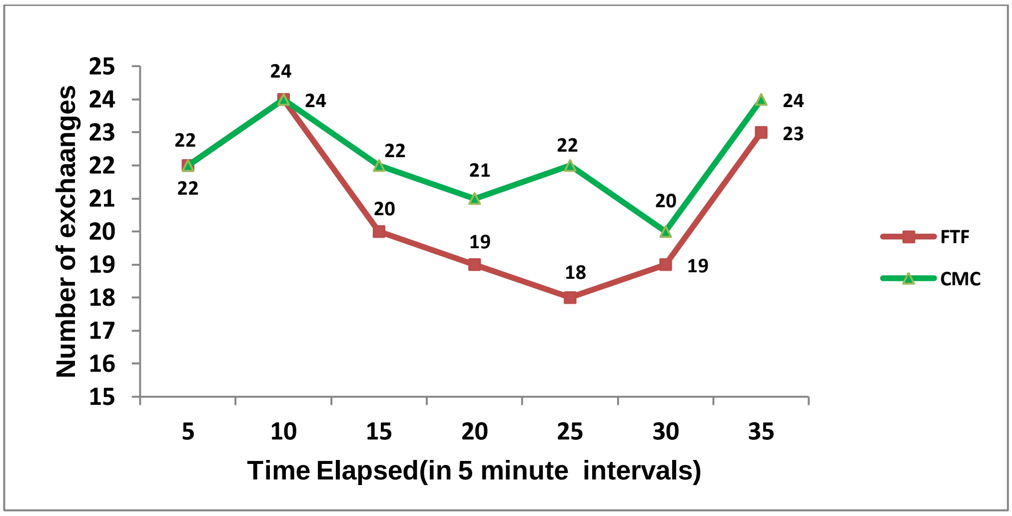


Figure 4.17: Total number of exchanges in FTF and CMC

4.7 Productivity

The results presented so far have been largely focused towards human factors. In this section, the productivity of the users is presented and discussed. Productivity has been assessed for both the team and each user by allocating points for various features of the task which have been completed successfully. These points are totalled and the productivity then effectively represents the total number correct changes between the initial version and final version of the model. For calculating the productivity of the tasks (i.e. FTF and CMC) each contains four worksets and each workset has five items. Generally each workset is allocated 2.5 points and each item has 0.5 points so if a team finishes 5 items for each workset they receive 2.5 points and if the team finishes all the four workset it receives ten points. Every effort has been made to make the point allocation procedure as consistent as possible but it has to be recognised that there is inevitably a degree of personal judgement involved.

The results for productivity averaged over all the experiments are presented in Fig. 4.18. As can be seen after the initial 5 minutes, productivity for CMC is higher than FTF. When looking these results, it is important to remember that none of the users had previously undertaken any technical tasks using CMC or Revit and so they were achieving these results using an unfamiliar mode of communication and working. The cumulative productivity for CMC is 7.4 and 6.3 for FTF. These results in the current work are not directly comparable to any in the literature, and the principal differences are in the nature of the tasks, and the group sizes. Therefore any comparisons should be made with care. However, there would seem to be agreement with Bordia (1997) who also found that, with time limited tasks which do not particularly require social interaction (see Section 2.4.3.1), productivity in CMC is higher than in FTF. Additionally, the current results partially concur with the work of Hewage et al. (2008) who found, for a construction activity, higher team productivity in CMC than FTF, even though their task used was implementation (rather than design) and the group size was around 15 (see Section 2.5). This is in contrast to the findings of Barkhi et al. (1999) who saw higher team productivity in FTF than in CMC (see Section 2.4.1), but their experiments had tasks with no time limit. It would seem that the higher productivity is found in CMC where a time limit is imposed on the tasks.

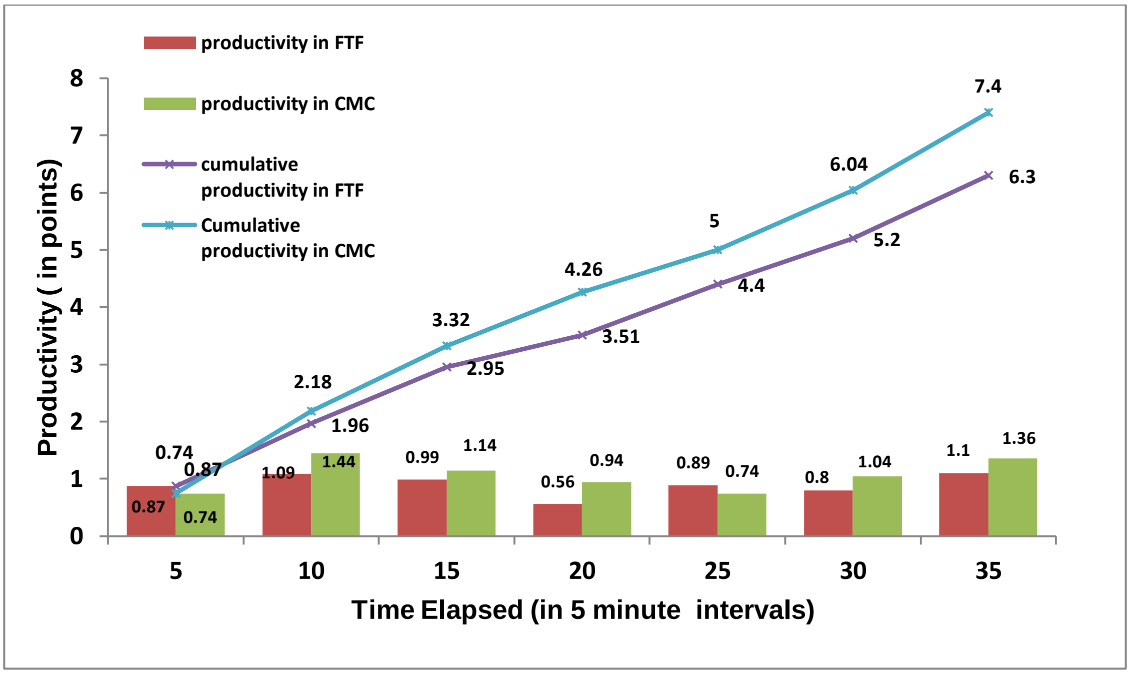


Figure 4.18: Productivity and cumulative productivity in FTF and CMC

4.8 Behaviour Profiles

This section discusses the behaviour profile for users during the experiments (i.e. how users behaved while discussing their task). The above performance measures are all quantitative and while giving aspects of human behaviour, they don't say anything about the types of people who were participating and the personal features of their participation. For each user, a behaviour profile has been constructed. The profile consists of three regions (e.g. Fig. 4.19), the first one shown on the left represents positive emotions, the second in the middle represents neutral emotions and the third on the right represents negative emotions. Each category consists of many emotions as follows:-

1. Positive emotions: e.g. Cooperative, Confident, Leader, Emphasizing, Committed, Optimistic, Patient, Respectful.
2. Neutral emotions: e.g. Cautiousness, Confused, Satisfied, Surprised, Worry, Reluctance.
3. Negative emotions: e.g. Domineering, Shy, Aggressive, Avoidance, Deceptive, Clowning, Depressive, Selfish, Disappointed, Doubtful, Pessimistic, Mocking.

As mentioned in the Section 2.8.2, the above classification is based on the work of Ekman, 1993; Kopelman et al, 2006; Mellers et al, 1999 on feeling classification where the categories are termed "natural emotions". The ideal curve is defined as when each user works in the most effective manner resulting in the positive profile scoring of 5 out 5 and 1 out of 5 for the neutral and negative profiles. The results for each user are obtained by evaluating the user's performance during the experiment. To collect the data from the users, the evaluation form consisting of 26 questions divided into the 3 categories (i.e. positive, neutral and negative) was devised (see Section 3.4.4 and Appendix E). Each category has questions to elicit the user's propensity for a particular behaviour during the experiment. The score for each item ranges from 5 (very high) to 1 (not at all). The average score for each question for all users are presented below in Figs 4.19 and 4.20 for FTF and CMC respectively. Additionally the average for each category has been computed and is represented by dotted lines. Two sets of points are given, the red one, being the average of the behaviour profiles for User1 and green one for User2. Comparisons are made between the two types of users during FTF and CMC.

While it may be argued that there is no especial reason to distinguish between the two users in a team, the results do show a distinction between User1 and User2. On average, User1 has a "better" behaviour profile than User2 in FTF, as shown in Fig. 4.19, with significantly higher positive emotions and lower neutral emotions but these are countered somewhat with higher negative emotions. Since which of the two users is designated User1 is determined simply by observing which user naturally takes more direct control of the computer in FTF, it is interesting that either the user with higher positive emotions should also be the one who takes more of a leadership role, or the one who ends up as more active is the one with a better behaviour profile in the collaboration. While there is clearly a correlation between these two factors, within the current results, it is impossible to determine which factor is causal.

Although the labelling of users determined in FTF is carried over into CMC, in the latter, both users have a computer and equal rights and access to the central Revit file. It can be seen in Fig. 4.20 that there is a marginal improvement in the average behaviour profile of User1 under CMC, but it is the marked improvement to User2 that is most noticeable, to the extent that User1 and User2 under CMC have similar behaviour profiles. The difference between the two users that exists in FTF is marginal in CMC, and it can be concluded that, at the very least, the CMC environment has no detrimental effect on behaviour and may even be able to foster a better behavioural approach to such collaboration. This finding is in agreement with the work of Riordan & Kreuz (2010) who stated that the users in CMC were less affected by emotional factors than in FTF (see Section 2.8.2).

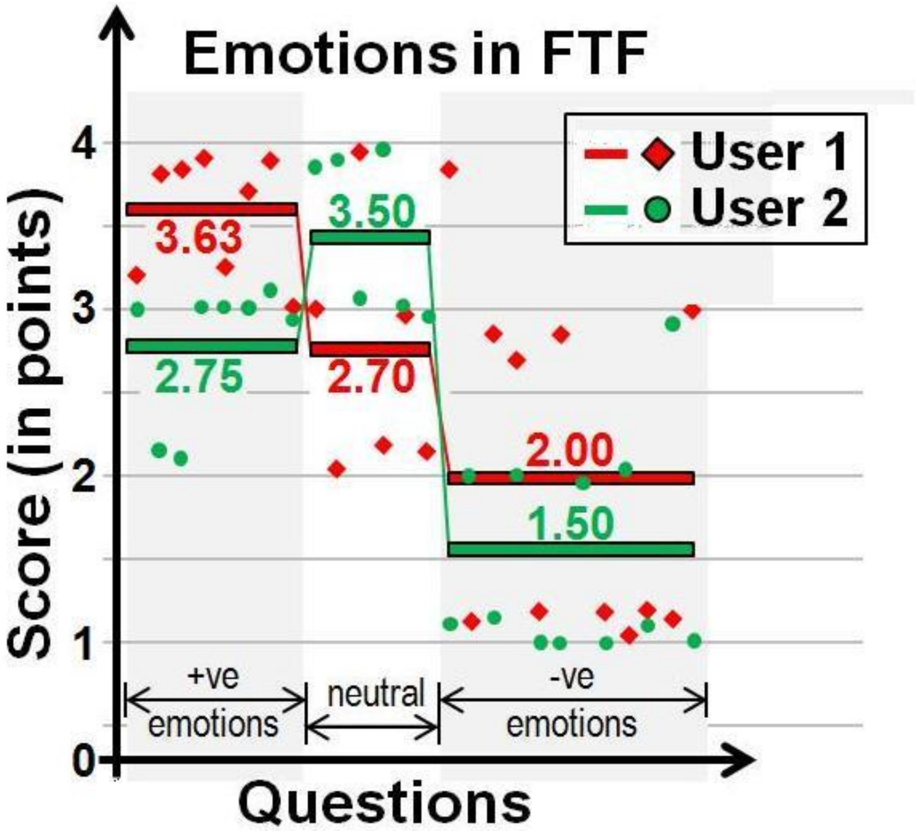


Figure 4.19: Behaviour profile for User1 and User2 in FTF

Looking in more detail at the behaviour profiles, it is observed that the users' behaviour in CMC is better than FTF. In CMC, User1's positive profile average is 3.75 while in FTF it is 3.63. For User2 looking at the positive profile in CMC, it is 3.50 on average whereas in FTF it is 2.75. For the neutral profiles the average score of User1 is 2.70 for both FTF and CMC methods while the User2s'score decreases from 3.50 in FTF to 3.00 in CMC (i.e. an improvement in behaviour for CMC). For the average FTF negative profile, User1 is 2.00 and User2 is 1.50 while in CMC User1 is 1.75 and User2 is 1.42, this means again that both users are close to the ideal in CMC. So overall, using this measure of performance, the users did better in CMC than FTF (Riordan & Kreuz, 2010).

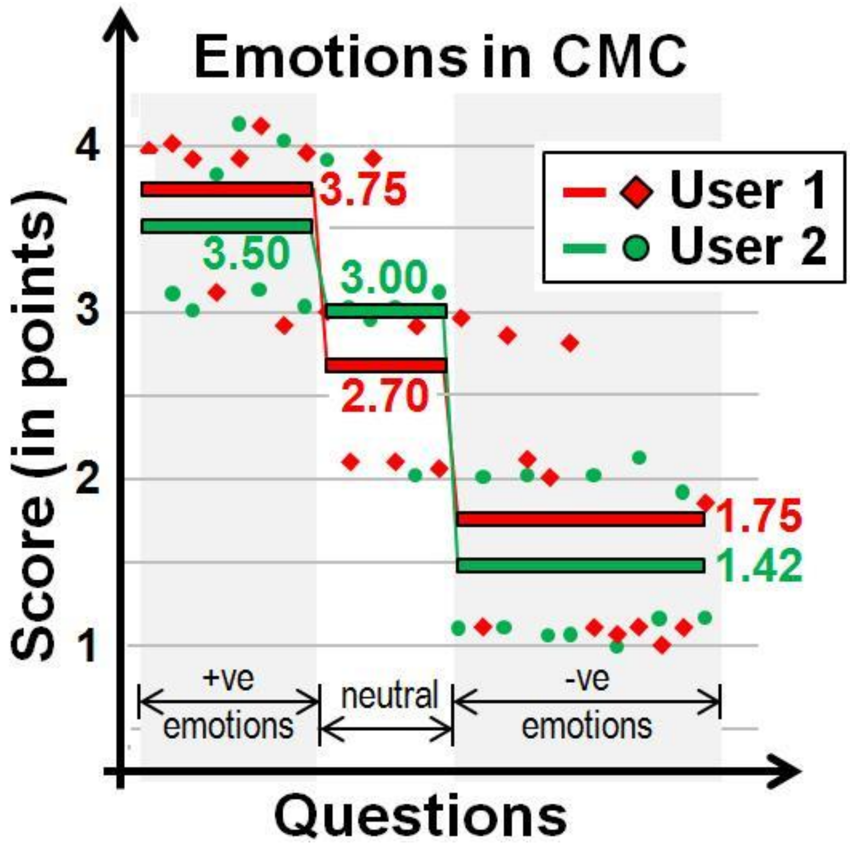


Figure 4.20: Behaviour profile for User1 and User2 in CMC

4.9 Speech Rate

Speech rate can be defined as the total number of words spoken during a specified time. It has been found useful to study and compare this rate in FTF and CMC to identify which method has higher speech rate. Speech rate can be affected by many factors such as psychological, cultural, demographic, and linguistic factors (Yuan et al, 2006). Another factor which is at least as important as the other factors is age, for example older speakers having a slower speech rate than younger people (Verhoeven, 2004). With regard to gender and dialect, they also have a significant effect on the speech rate, Quené (2005) mentioned that men speak 15% faster than women, and as one would expect non-native speakers have a slower speech rate of 20% than native speakers. Additionally, a shortage in information and experiences make the speech rate too slow and this lead to weak communication (Hincks, 2009).

In the experiments for this research the speech rate is presented as the total number of words said by a user in 300 seconds (i.e. in blocks of 5 minutes).

In FTF, Table 4.1 illustrates the total number of words said by each user during the experiment time intervals and Fig. 4.21 compares between the speech rate for User1 and User2, the results show that User1 has a speech rate of 0.61 words/sec while User2 has a rate of speech is 0.50 words/sec. The speech rate for User1 in the first half of the experiment is higher than User2 while in the second half of the experiment there is more equality. These findings consistent with results in the previous Figs. 4.2 and 4.6 which showed that User1 exerted a high degree of dominance, especially in the early stages of the experiment and a high speech rate is consistent with this finding. Conversely, and following the work of Kallinen and Ravaja (2004), emotional states can affect the speech rate, and hence the emotional state be judged from the speech rates. They concluded that a low rate means user is hesitating and feels anxious, and such a conclusion could possibly be valid in these results.

Table 4.1: Average of total words said by both users in FTF

Time(minute)	**5**	**10**	**15**	**20**	**25**	**30**	**35**
User1(words)	186	207	187	160	132	220	185
User2(words)	124	138	145	150	198	112	175

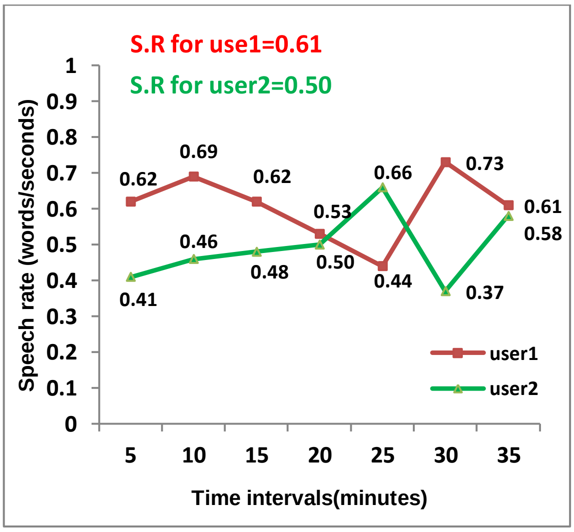


Figure 4.21: Speech rate for users in FTF

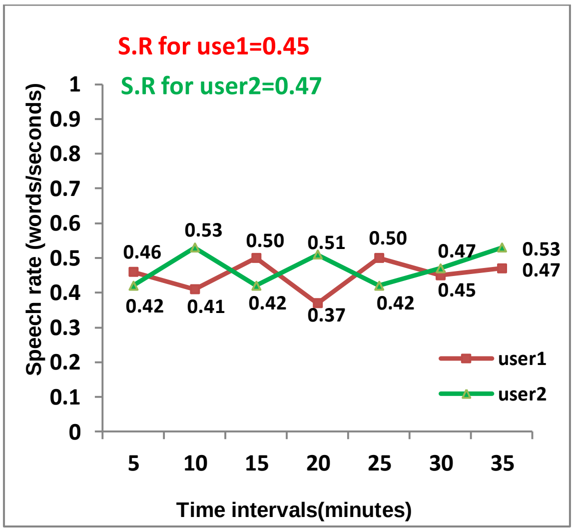


Figure 4.22: Speech rate for users in CMC

In CMC Table 4.2 shows the total number of words said by both users during each time interval and Fig. 4.22 compares the speech rate for both users. As can be seen, the pattern of behaviour is very different to that for FTF with the speech rate for both users being roughly similar. Generally speech rate in CMC is lower than that in FTF, User 2's speech rate is slightly higher than User 1's, however the difference between them is very small with User1 speaking 0.45 words/second while User2 has 0.47 words/second. These results are consistent with those in Figs. 4.3 and 4.7.

Table 4.2: Average of total words said by both uses in CMC

Time(minute)	**5**	**10**	**15**	**20**	**25**	**30**	**35**
User1(words)	140	123	150	113	150	134	140
User2(words)	127	160	128	152	128	140	160

These differences indicate that the users in CMC are less affected by emotional factors and the rhythm of speech slower than FTF. By using CMC the user becomes more involved with computer work like writing and changing items on screen instead of talking to the other user. Generally the trend of the speech rate in FTF and CMC also consistent with the Figs. 4.11 and 4.12 above for working time.

4.10 Summary

In this chapter the differences between computer mediated communication (CMC) and face to face communication (FTF) as found in the results of the experiments are discussed. The results have emerged from a thorough analysis of the experiments. At the start of this work, it was expected that the results for FTF would be better than those for CMC, but generally the results have proved that the efficacy of CMC is better than that of FTF and the following points illustrate these advantages.

1. The total number of non-work related words is higher in FTF than CMC which indicates that more time is spent on social factors. In general, wasted time is higher in FTF, and working time is higher in CMC. Additionally, the users usually avoid

side conversations in CMC and concentrate on their work as compared to FTF communication, making CMC slightly better than FTF from practical point of view.

2. CMC seems to reduce the differences between users and to equalise emotional factors, resulting in near equal participation. The behaviour profile of the users also significantly improves (to near ideal) from FTF to CMC.
3. There is clearly a more even distribution of time spent between the two users in CMC, which strongly indicates that in CMC each member can participate more freely regardless of any other factors like age group, experience, emotional factors, etc.
4. Productivity in CMC is higher than in FTF.
5. Speech rate in FTF is higher than in CMC. In FTF User1 has a higher speech rate than User2 whereas in CMC, they are almost equal. Speech rate is an indication of the user states during the experiment.

Chapter 5

Comparison between Team Productivity in FTF and CMC

5.1 Introduction

This chapter covers team productivity in FTF and CMC and considers what factors influence this. It addresses the relationships between productivity and factors such as the number of words spoken, time and the number of exchanges. This chapter is divided into four sections as follows:-

1- Section 5.2 provides details about team productivity for FTF and CMC and shows which method is better from a productivity aspect.
2- Section 5.3 indicates the factors that have had an effect on team productivity; these are classified into four main factors with each factor being studied independently to establish its relationship with team productivity.
3- Section 5.4 considers the relationship between team productivity and some of the indicators identified during the preceding analysis of the experiments, such as work-related words, the number of exchanges, working time and wasted time.
4- Section 5.5 considers the differences between the productivity of a single person working alone and the productivity achieved by a team, this being done for the same engineering design task and within the same limitations.

5.2 Team Productivity

Team productivity is one of the most important indicators of team performance and in a commercial environment can be considered as the ultimate objective in the collaboration process (The team productivity calculation is explained in Section 4.7). Table 5.1 illustrates the results of team productivity for the 20 experiments using FTF and 20 using CMC, as well as the type of team according to the users' expertise, (this is explained in Section 3.3.1). It is noticeable that the average team productivity for CMC is 15% higher than for FTF, this result is consistent with Bordia (1997) who indicated that the team in the CMC performed better in the tasks than in FTF by around 21% when the time is restricted (see Section 2.4.3.1). In general, productivity for CMC is higher than FTF in 75% of the experiments and for FTF it is higher 20% of the experiments and it is equal in experiment 4. Clearly, no team managed to obtain a full score (i.e. 10 points). This could have been due to several reasons such as the users were not familiar with Revit, or the time limit of 35 minutes for the task was insufficient, and sometimes they left items untouched because they did not think they needed to amend them. From Table 5.1 it can be seen that team type Expert-Expert has a high score in team productivity in FTF and CMC while team type Novice-Novice has a low score for both methods. The average of team productivity for Expert-Expert in FTF and CMC is 2.56 times higher than this average for Novice-Novice, this result concurs with the work of Kavakli et al. (1999) who mentioned that the team productivity made by the expert designer was three times higher than the novice designer (see Section 2.8.1). Table 5.1 shows the productivity of other team types such as Expert-Junior expert, Expert-Novice and Junior expert-Novice ranges between the two extremes (i.e. Expert-Expert and Novice-Novice).

Table 5.1: Team productivity and the type of teams in FTF and CMC

Experiment Number	Team type	Productivity (points) in FTF	Productivity (points) in CMC
1	Expert-Expert	8.25	7.75
2	Expert-Junior expert	7.50	8.34
3	Expert-Novice	5.00	6.75
4	Expert-Expert	8.50	8.50
5	Novice-Novice	5.50	6.75
6	Expert-Junior expert	7.75	8.50
7	Expert-Expert	8.50	8.25
8	Junior expert-Novice	6.00	7.50
9	Novice-Novice	3.63	4.00
10	Novice-Novice	3.25	3.00
11	Expert-Junior expert	5.50	8.37
12	Junior expert-Novice	5.62	7.50
13	Novice-Novice	7.00	5.50
14	Expert-Expert	8.37	8.50
15	Expert-Novice	6.00	7.75
16	Expert-Novice	7.00	7.87
17	Junior expert-Novice	6.12	7.75
18	Junior expert-Novice	6.50	7.62
19	Expert-Novice	6.25	7.87
20	Expert-Junior expert	7.00	8.00
Average		**6.30**	**7.40**

Table 5.2 illustrates the differences between the averages of team productivity for each type of team. It is evident that the averages in CMC are higher than in FTF in all the team types, with the exception of type Expert-Expert and Novice-Novice. For the team type Expert-Expert, this may indicate that the users in this category had a good score in two methods and good expertise level. Additionally, the differences between the two methods

are small, but they functioned better in FTF than with CMC. This might be related to the age group and the fact that the users are less familiar with the software and therefore prefer to work in FTF. Except for the two team types with equal pairings (i.e. Expert-Expert and Novice-Novice), the results show that productivity was higher in CMC than in FTF, and the differences between the two are significantly higher than that for team with equal pairings. This could be because the users in these types were more comfortable with CMC, and/or they prefer to work with computers and therefore they achieved good results. There is probably also an age factor involved since most of the users in the unequal pairings were significantly younger than the Expert-Expert teams, and thus more familiar with new technology. For Novice-Novice, there is a only a small difference between productivity in FTF and CMC, but productivity in both methods is low, and there is much bigger standard deviation, so it is less easy to draw conclusions.

Table 5.2: Averages of team productivity in FTF and CMC

Team type	Average of team productivity in (points) in FTF	Standard deviation	Average of team productivity in (points) in CMC	Standard deviation	Differences in productivity (points)
Expert-Expert	8.40	0.10	8.25	0.30	0.15
Expert-Junior expert	7.03	0.88	8.30	0.18	1.87
Expert-Novice	6.06	0.75	7.56	0.42	1.50
Junior expert-Novice	6.06	0.31	7.59	0.10	1.53
Novice-Novice	4.92	2.93	4.80	1.60	0.12

5.3 Factors Affecting Team Productivity

This section examines the factors influencing team productivity and the impact of each factor on the productivity score. Productivity is an outcome of a set of elements influenced by a variety of factors including external factors such as those of the environment and the circumstances of the experiment. There is also a strong relationship between team productivity and the environmental quality, such as cold, heat, noise and light (Roeloelofsen, 2002), these being outside the scope of this research. Additionally, other factors are related to the characteristics and behaviour of the team members, these being highlighted by this research. These factors can be classified into four main groups:-

- Emotional profile
- Expertise level
- Cultural differences
- Prior relationship and familiarity

5.3.1 Emotional Profile

This factor is one of the factors that affects the team productivity. The emotional profile for each user in FTF and CMC is described in Section 4.8; the results reveal that there are significant differences between the profile averages of User1and User2 in all the categories for FTF. These differences were higher than in CMC with the emotional profile for users in CMC being much closer. In this way, CMC, in contrast to FTF, achieved a higher productivity and a good degree of collaboration, this being represented by the number of exchanges.

In this section it is useful to study each type of emotion separately, whether positive, neutral or negative, to establish the actual relationship between the type of emotion and team productivity.

5.3.1.1 Total Positive Emotions

Figure 5.1 shows the relationship between total positive emotion and team productivity, for each team in both FTF and CMC. The total positive emotion for each team has been calculated by adding the score of positive emotions for the two users. Generally, there is a strong positive correlation between team productivity and positive emotions, with the correlation factors as 0.8849 and 0.8658 for FTF and CMC respectively. Equally, the slope of best-fit straight lines for FTF and CMC are around 1.2-1.3 (i.e. near unity), which shows good proportionate interdependence of team productivity and positive emotion. Furthermore, it is also somewhat surprising that the two slopes (for FTF and CMC) are nearly the same because this says that the strong correlation between a team's productivity and its positive emotion is independent of the method of communication.

Figure 5.1 proves that there is a positive relationship between the total of the positive emotions and the team productivity score, this result is in agreement with the work of Feyerherm & Rice (2002) who stated that team productivity increased when the team members had positive emotions, this bringing about a positive relationship between them when working on a specific task (see Section 2.8.2). However, one cannot say that team productivity depends solely or greatly on this factor because further study is needed on other factors to establish the real impact of each of them on team productivity.

As can be seen in Fig. 5.1, the productivity score for teams belonging to category Expert-Expert are less affected by total positive emotions than the other categories (i.e. total positive emotions increase but team productivity is still the same), in contrast to other categories. Since this spread is the largest (i.e. team productivity increases when total positive emotions increase) in category Novice-Novice and present to a lesser degree in teams Expert-Junior expert, Expert-Novice and Junior expert-Novice, this means there is an effect from the total amount of positive emotions on team productivity in these types of teams and therefore team productivity is greatly affected by this factor in these categories besides other factors such as the differences in the teams' levels of expertise, cultural differences and prior relationships.

It is significant to mention here that the total amount of positive emotions in CMC is higher than FTF in 75% of the total experiments and the total in FTF was higher than CMC in 20% of total experiments; however, they were equal in total in experiment 4 which was equivalent to 5% of the total number of experiments. These results concur with the results in Table 5.1.

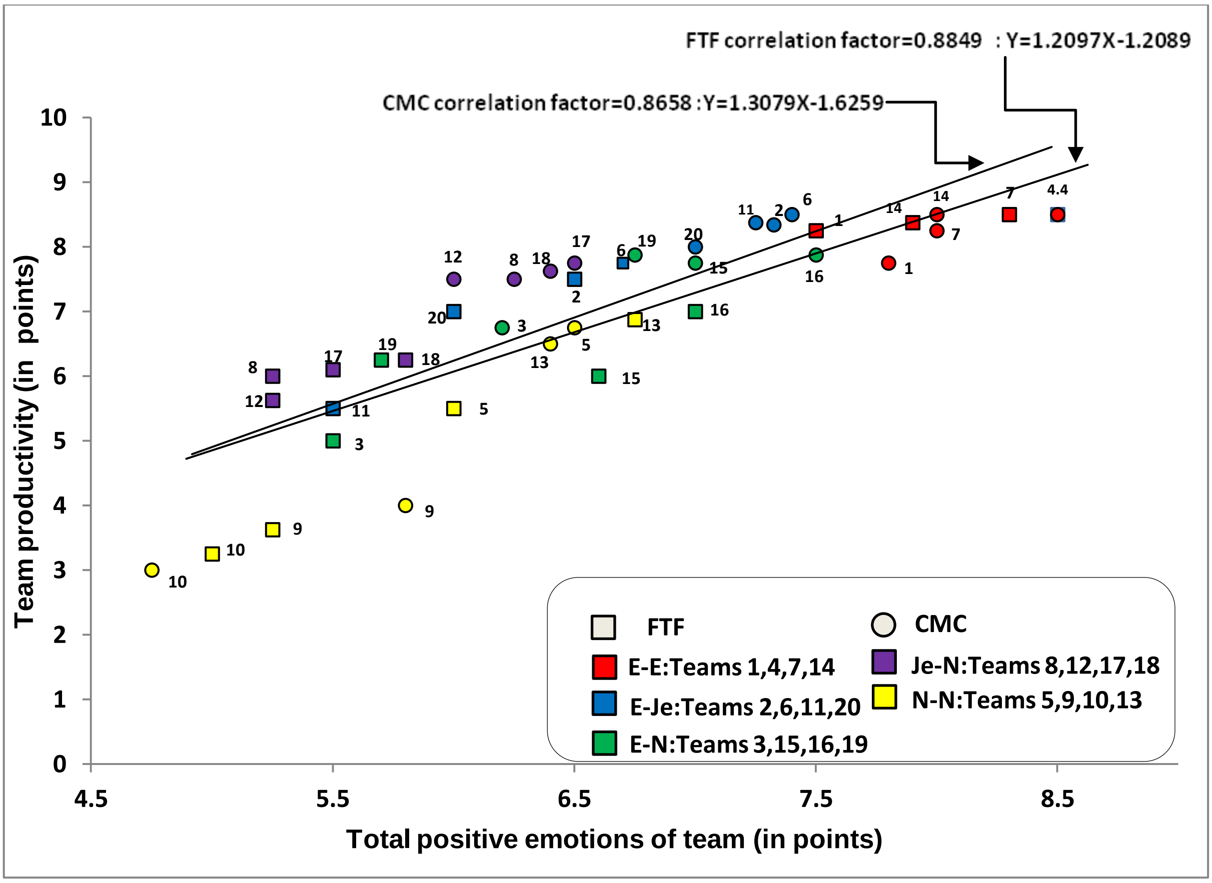


Figure 5.1: Total positive emotions of team and team productivity in FTF and CMC

5.3.1.2 Total Negative Emotions

For the negative emotions shown in Fig. 5.2, there is a strong negative relationship between team productivity and the total amount of negative emotions, this result concurs with the work of McColl-Kennedy & Anderson (2002) who stated that negative emotions reduce team productivity (see Section 2.8.2). The negative emotions for each team were calculated as the total amount of the positive emotions (i.e. by adding the score of negative emotions for User1 to User2). The correlation between the total amount of negative emotions and team productivity for FTF is stronger than for CMC, as indicated in the correlation factor of -0.8985 for FTF and -0.8074 for CMC. Additionally, the slopes of the two best-fit straight lines are negative, and is marginally higher in FTF than CMC. It can also be stated that the negative impact from negative emotions on productivity significantly outweighs the positive impact from positive emotions, since the negative slope (Fig. 5.2) is double the size of the positive slope (Fig. 5.1). For the category Expert-

Expert teams, the spread in the total negative emotions is considerable, but the team productivity is very similar, showing that the effect of the total negative emotions on team productivity is very small. Conversely, in other categories such as Novice-Novice, and to a lesser degree, teams Expert-Junior expert, Expert-Novice and Junior expert-Novice, the spread of negative emotions is also large but the productivity also varies. This means there is a definite link between the total negative emotions and team's productivity.

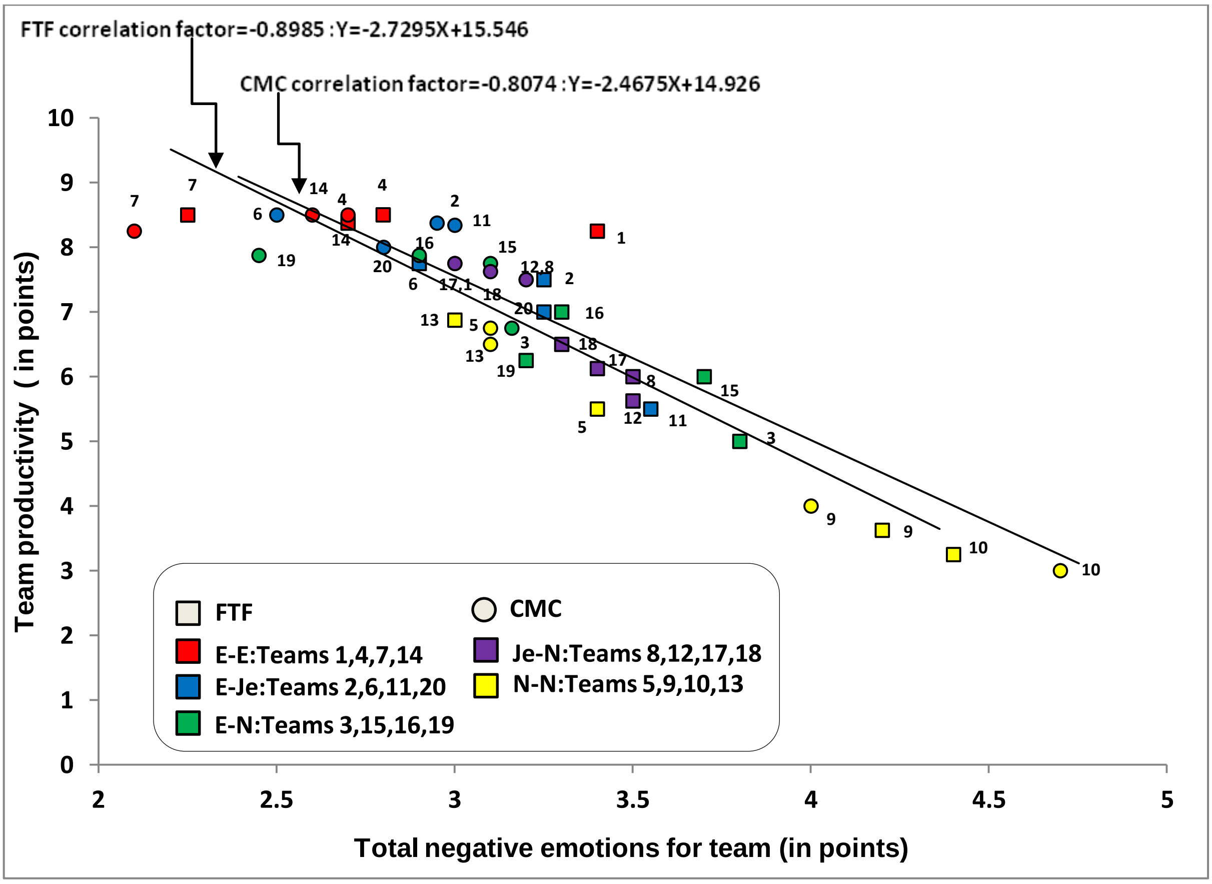


Figure 5.2: Total negative emotions of team and team productivity in FTF and CMC

The total negative emotions in CMC were less than in FTF in 85% of the total experiments and greater in CMC in 15% of the total experiments; this means the users in CMC exhibit a better emotional profile than in FTF. Generally, it is clear that the effect of these factors (i.e. total positive and negative emotions) may largely depend on the type of the team.

5.3.1.3 Total Neutral Emotions

Figure 5.3 shows the relationship between the total neutral emotions and team productivity for FTF and CMC. The total neutral emotion for each team has been calculated in the same way as the total of positive and negative emotions. Here, it can be seen that, there is very weak correlation between team productivity and this type of emotion. Furthermore, the slope of the two best-fit straight lines is reversed with positive slope in FTF and negative slope in CMC. It is interesting to observe in type Expert-Expert teams that there is large spread with high productivity and the productivity still the same in spite of total neutral emotions increase; while this is true to a lesser extent to all the other team types.

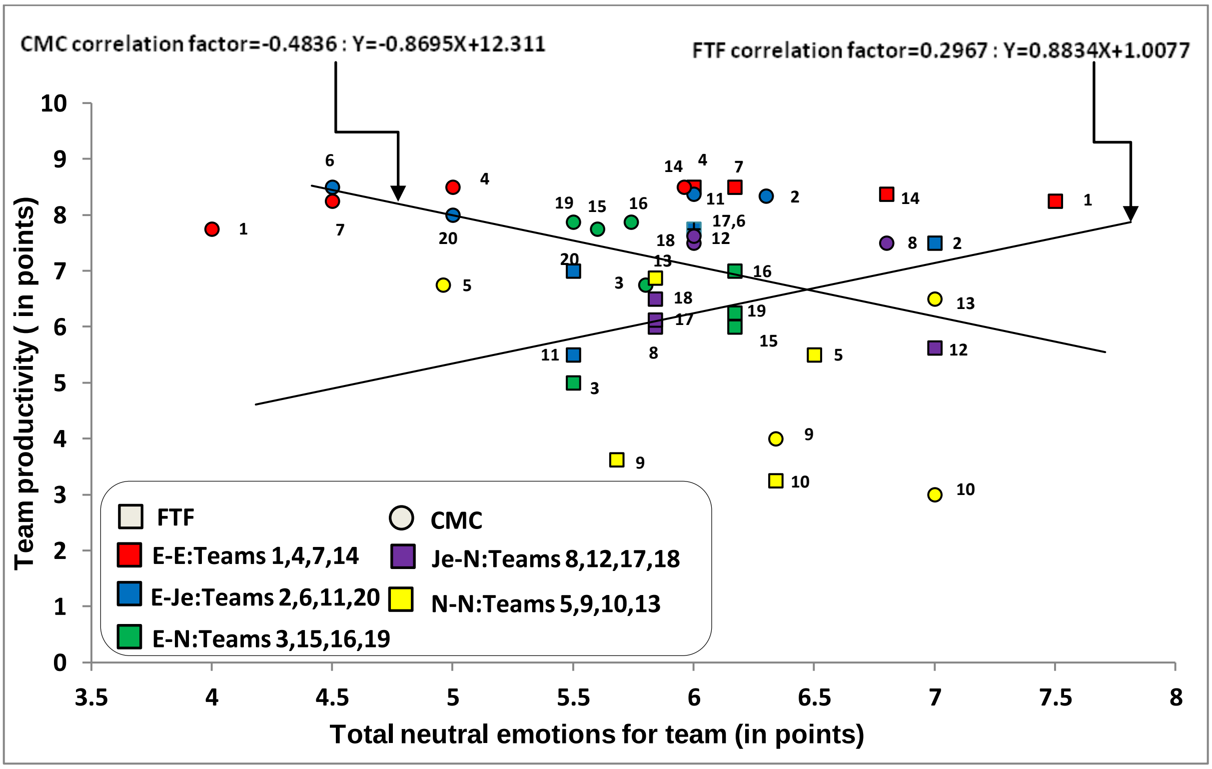


Figure 5.3: Total neutral emotions of team and team productivity in FTF and CMC

As there is no relationship between neutral emotions and team productivity, and this effect was only limited by positive and negative emotions, it was therefore deemed useful to concentrate further study on the impact of the total positive and negative emotions on team productivity. To aid a comparison of this factor (i.e. positive and negative emotions) with other factors such as team expertise, cultural differences and prior relationships and to study this factor properly, it has been found to be useful to combine the positive and negative emotions scores into one quantity which represents the differences between the total of positive and negative emotions.

Figure 5.4 shows the differences between positive and negative emotions for each team against the team productivity for that team. It is clear in Fig. 5.4 that there is very strong correlation for FTF (factor=0.9343) and also a strong correlation in CMC (factor=0.8852). The slope of the two best-fit straight lines is nearly the same. This difference between positive and negative emotions was found to be higher CMC than FTF for 85% of the experiments.

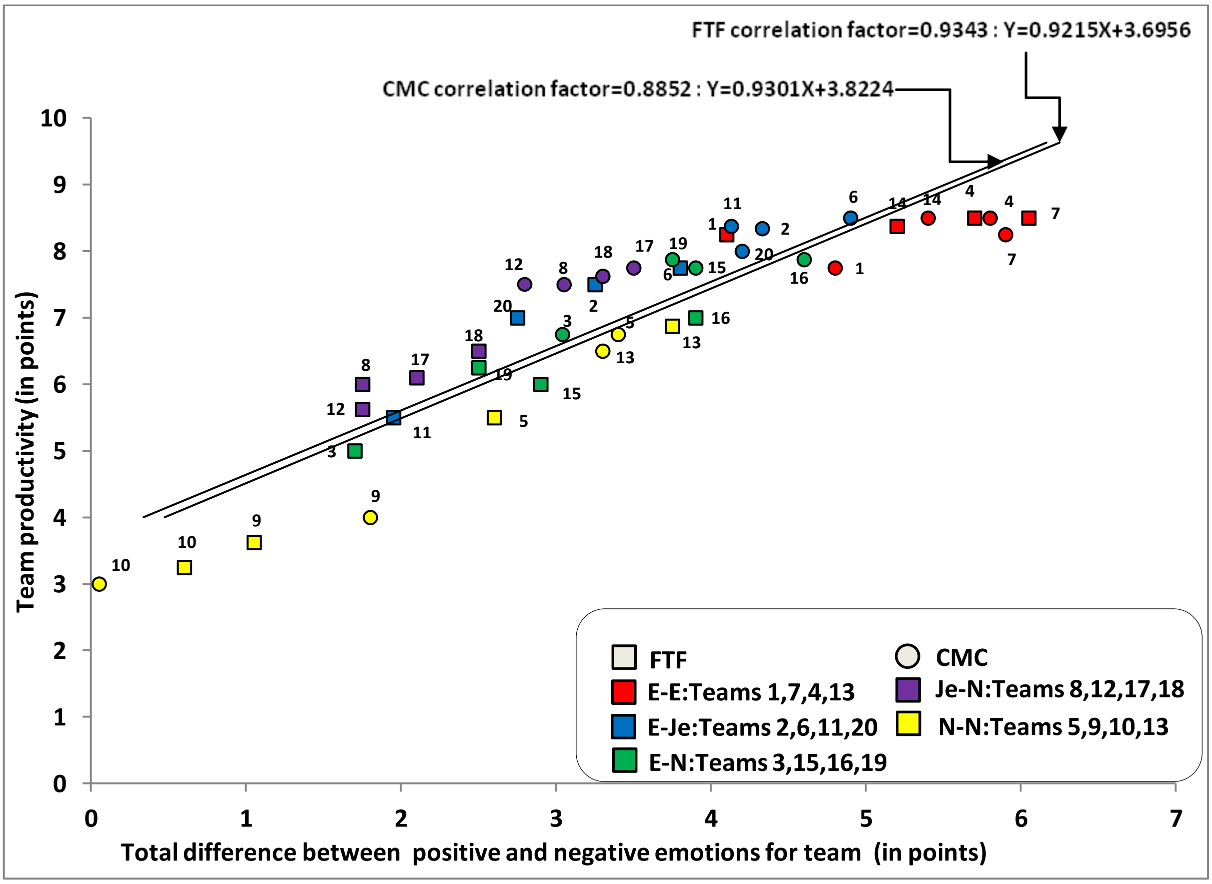


Figure 5.4: Total differences between positive and negative emotions for team and team productivity in FTF and CMC

5.3.2 Expertise Level

The level of expertise for any team is one of the most important factors affecting team productivity and it has a significant relationship with productivity, both in FTF and CMC (see Section 2.8.1). In this research the users have various expertise levels. In order to classify them as teams they have been divided into five main categories (see Section 3.3.1). The "expertise level" has been calculated as a summation of the two users' expertise for each team.

Figure 5.5 shows the relationship between the types of teams according to their expertise level and the productivity. Additionally, it illustrates all the team details, such as the team number, whether team members have the same cultural background or not, and whether they already knew each other before the experiment, and also the differences between the positive and negative emotion for a team. (The key in Fig. 5.5 explains the coding used for all these factors).

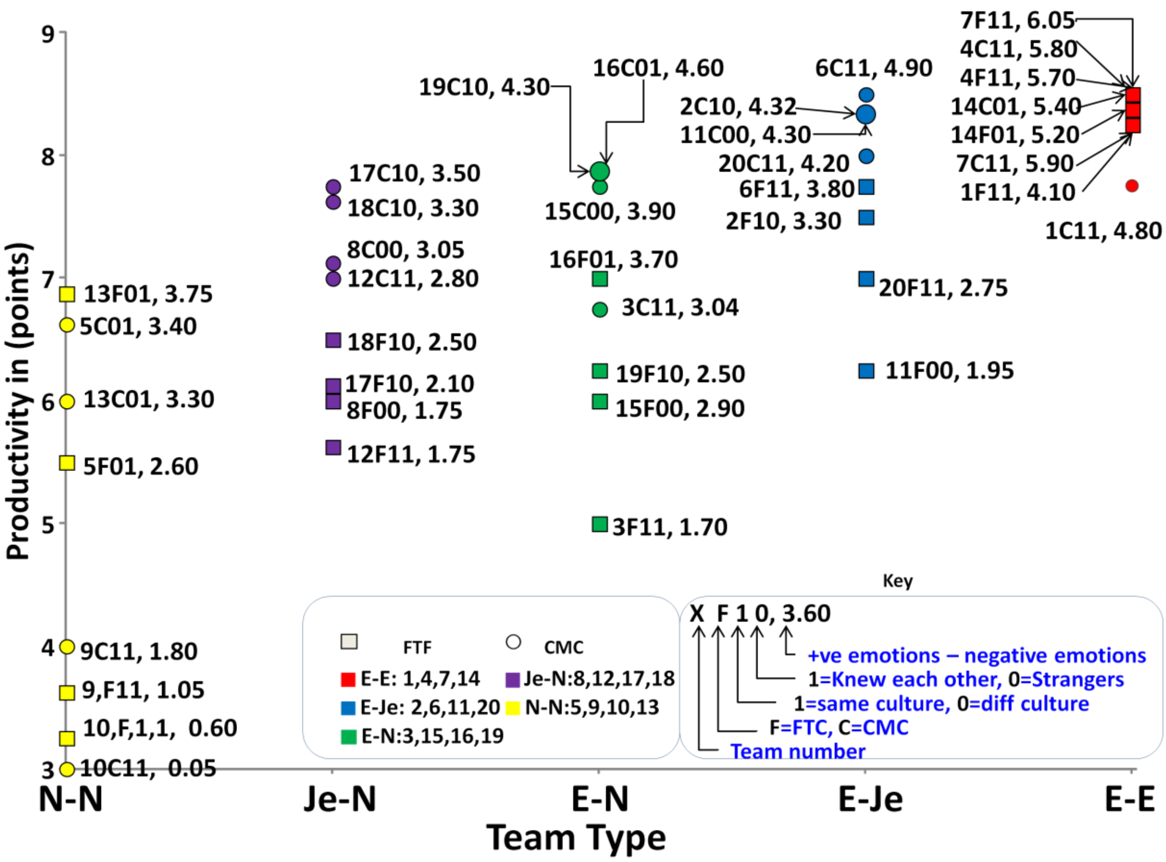


Figure 5.5: Team productivity and team type in FTF and CMC

It is evident from Fig. 5.5 that, productivity is most strongly related to team expertise and the other factors such as differences in emotions, cultural differences and prior relationship seem to have a lesser effect. The general trend shows the team type Expert-Expert (in red) has high productivity and team type Novice-Novice (in yellow) has low productivity (with greater variability), with the other team types located between them. It is clear that even in a single team type (which has the same expertise level); there are differences in team productivity, which would then be due to factors other than expertise level, and Sections 5.3.3 and 5.3.4 will discuss the effect for each factor on team productivity.

However, it is true that, even within a single team type, there is variation in the total number of years of experience. For example, in the Expert-Novice team type, the sum of the team member experience ranges from six years (Team 3) to 12.5 years (Team 19), and there is the pattern observed of the lower experienced teams having the lower productivity values. This is also evident for team type Junior Expert-Novice (but less so for the other teams where there was not much of a spread of experience, or spread of productivity values). Therefore, while other factors like positive/negative emotions or prior relationship can have an impact; it is probable that it is experience (both team expertise and individual experience) that has the greatest influence on productivity.

5.3.3 Difference between Positive and Negative Emotions

This section explains the relationship between the difference in positive and negative emotions for a team with team productivity. For example, for team type Expert-Expert, when comparing between Team 1 and Team 4 in CMC, the users in each team had the same expertise level, the same culture and had known each other previously, but the team productivity of Team 1is lower. Looking at the possibly causes for this, Fig. 5.5 indicates that main difference is their emotional profile. The total difference between positive and negative emotions for Team 4 is higher than Team1. This can also be observed with the results for Team 7, where its productivity is slightly higher than for Team 1 in FTF.

For team type Expert-Junior expert, it is clear that the ranking of the team’s productivity essentially depends on the ranking of the difference in positive and negative emotions, be that in FTF or CMC. For example, for Teams 6 and 20 in CMC, the users have the same level of expertise, the same culture and knew each other previously, but the productivity for Team 6 is higher than for Team 20, with the total differences in positive and negative emotions for Team 6 being higher than for Team 20. As regards Team 6 and Team 20 for FTF, the productivity score for Team 6 is higher than for Team 20 and possibly the reason for this is the difference between positive and negative emotions for Team 6 is higher than for Team 20, because all other factors investigated (such as expert level, culture difference and prior relationship) are the same for both teams.

For the team type Expert-Novice, it again can be observed that team productivity varies according to the total difference between positive and negative emotions. For example, for Teams 3 and 19 in CMC, the users have the same expertise level, the same culture and users in Team 3 have a prior relationship while the users in Team 19 were strangers. This indicates that the total difference can be seen in the positive and negative emotions, which for Team 19 is higher than for Team 3. Here, two factors are affecting the productivity score difference (i.e. differences in emotional profile and prior relationship). For Teams 16 and 3 in FTF, it is clear that the users were at the same expertise level and knew each other in both teams, but they were culturally different in Team 16 and have the same culture in Team 3. Yet, the figure shows that team productivity for Team 16 is higher than for in Team3, and this difference is thus due to differences between positive and negative emotions and cultural differences.

In another example for the team type Junior expert-Novice, the general trend indicates the difference in positive and negative has a big effect on the productivity scores for the teams. As regards Teams 12 and 17 in CMC, the users in each team have the same expertise level, the same culture and knew each other in Team 12 but were strangers in Team 17. The difference between positive and negative emotions for Team 17 is better than for Team 12, here, the difference in productivity related also with two factors differences in positive and negative emotions and prior relationship. This is also applicable for Teams 12 and 18 in FTF.

Lastly, for the team type Novice-Novice, again it seems the emotional profile is the main factor affecting the team productivity scores. For Teams 13 and 5 in FTF, the users have same expertise level (i.e. with no experience), knew each other beforehand and the users in two teams from different culture, but the productivity for Team 13 is higher than Team 5, the main reason is the difference in positive and negative emotions for Team 13 which is higher than for Team 5. For Teams 5 and 10 in FTF and CMC, the users have the same expertise level, knew each other before, have the same culture in Team 10 and different cultures in Team 5. The total difference between the positive and negative emotions for Team 5 is higher than for Team 10. Here, the difference in productivity between the two teams would be due to differences in positive and negative emotions and differences in culture.

Generally, from the Fig. 5.5 and the previous analysis, it is evident that the difference in positive and negative emotions is the second important factor affecting team productivity (after team expertise) in most of the team types.

5.3.4 Cultural Differences and Prior Relationship

In this section, the impact of cultural differences and prior relationships on team productivity is examined. The experiments have involved users who have come from a variety of cultures. Some were already acquainted and the rest were strangers. According to the results in Sections 5.3.2 and 5.3.3, it is apparent that culture differences and prior relationship have a limited effect on team productivity when compared with other factors such as the level of expertise or differences in emotional profiles.

A good example is found among the Expert-Expert teams in Fig. 5.5, all the teams have the same expertise level, and all the team users knew each other beforehand, but Team 14 is the one team with users from different cultures. However, there is no notable difference in the productivity of Team 14 for both CMC and FTF, compared to the other productivity values from other Expert-Expert teams. Therefore, it would suggest the difference in cultural background has had very little influence on productivity. Alternatively, both Teams 6 and 20 have members who are from the same culture, who knew each other beforehand, and in CMC, showed some differences in emotional profiles score (4.90 vs 4.20) but Team 6 had a higher productivity, so this difference in productivity cannot be attributed to cultural similarity, but some other factor.

While the small sample size must be noted, yet, where there can be observation made, it is that prior relationship has not had much effect on team productivity. For example, within the same expertise level of Expert-Junior expert, Team 2 has a higher productivity score than Team 20 (in both FTF and CMC) in spite of the users in Team 20 having known each other beforehand and those in Team 2 were strangers. If prior relationship was to have an effect, then it would have been a positive effect (unless, of course, the relationship was a bad relationship). Similarly, in another example, the productivity in CMC for Teams 6 and 11 (both with Expert-Junior expert expertise) are about the same and high, but in FTF, Team 6 has much higher productivity than Team 11. Team 6 members were previously acquainted, but members in team 11 were strangers. If productivity was significantly affected by whether team members knew each other beforehand, then this effect would be the same in FTF as in CMC, and there would not be a big difference in FTF productivity scores when the same two teams have near identical productivity scores in CMC. This is applicable with the other team types such as Expert-Novice, Junior expert-Novice and Novice-Novice. Clearly, in these experiments when the task is fairly focussed and of short duration, prior relationship has little effect also on team productivity.

Overall, the data in Fig. 5.5 shows that team productivity sometimes increases, and other times decreases, with cultural differences and prior relationship, i.e. there is no clear unambiguous pattern. With the amount of the data available, it is therefore difficult to conclude exactly what is the effect of cultural differences or prior relationship, other than that they seem to have no strong effect.

5.3.5 Summary of Factors Affecting Productivity

The conclusions from this section are that the factors affecting team productivity in FTF and CMC can be classified according to two main levels.

- The team expertise level (i.e. team type), and
- The difference between positive and negative emotions for a team.

There may be some effect from cultural difference and prior relationship, but it is difficult to determine the type and magnitude of these effects at this stage because this particular point can only be tested from a small subset of the teams, and hence sample size was very limited.

5.4 Comparison between Team Productivity in FTF and CMC

This section compares team productivity in FTF and CMC and studies the relationship with elements related to team productivity, such as the total number of work-related words, the number of exchanges, working time and wasted time.

5.4.1 Team Productivity and the Total Number of Work Related Words

In a collaborative task more productivity typically requires more communication relevant to the problem. The quantity of communication largely depends on the exchange of speech between people. Figure 5.6 shows the relationship between team productivity and the total number of work-related words stated by the users over time for FTF. It can be seen that there is a weak correlation between them, as indicated in the correlation factor of 0.5766.

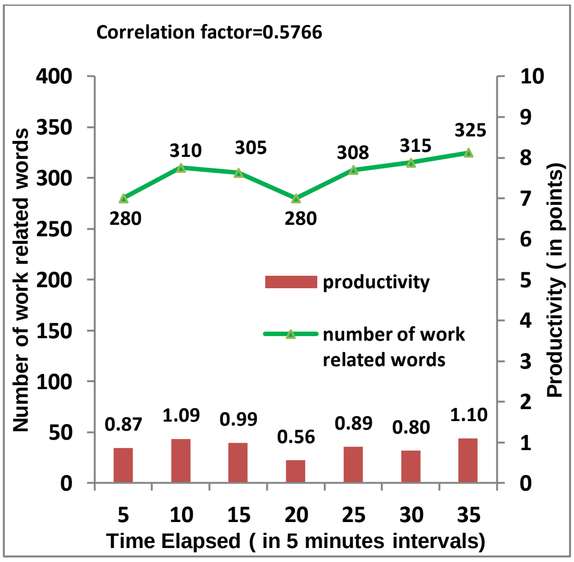


Figure 5.6: Team productivity and number of work related words in FTF

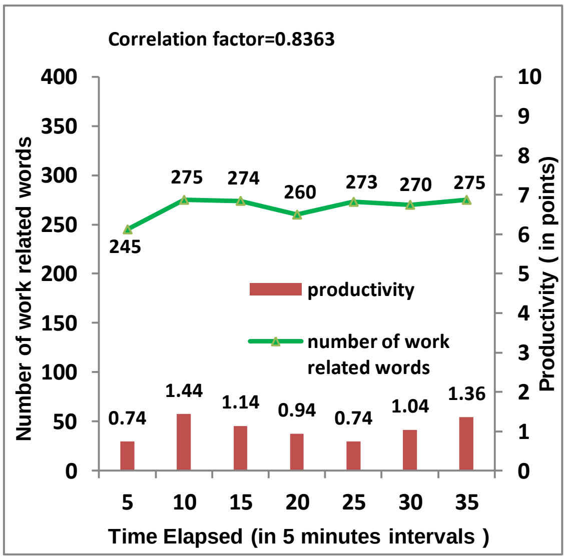


Figure 5.7: Team productivity and number of work related words in CMC

For CMC as shown in Fig. 5.7 there is a fairly strong correlation between team productivity and the total number of work-related words over time, as indicated by the correlation factor of 0.8363. This possibly indicates that in CMC people concentrated more on their work. This finding is supported by the greater number of work related words spoken in CMC (see Section 4.2.2).

Figure 5.8 shows the relationship between the percentage of work-related words in relationship to the total number of words and team productivity in FTF and CMC. Generally, there is a weak correlation between team productivity and the percentage of work related words for FTF and a moderate correlation for CMC. For FTF the correlation is weaker than for CMC, as indicated in the correlation factor of 0.5959, while for CMC this was 0.7326. It is clear that the two slopes of the best-fit straight line (CMC and FTF) are nearly the same, and thus productivity is related to the number of work related words in the same way, regardless of whether the communication is by CMC or FTF.

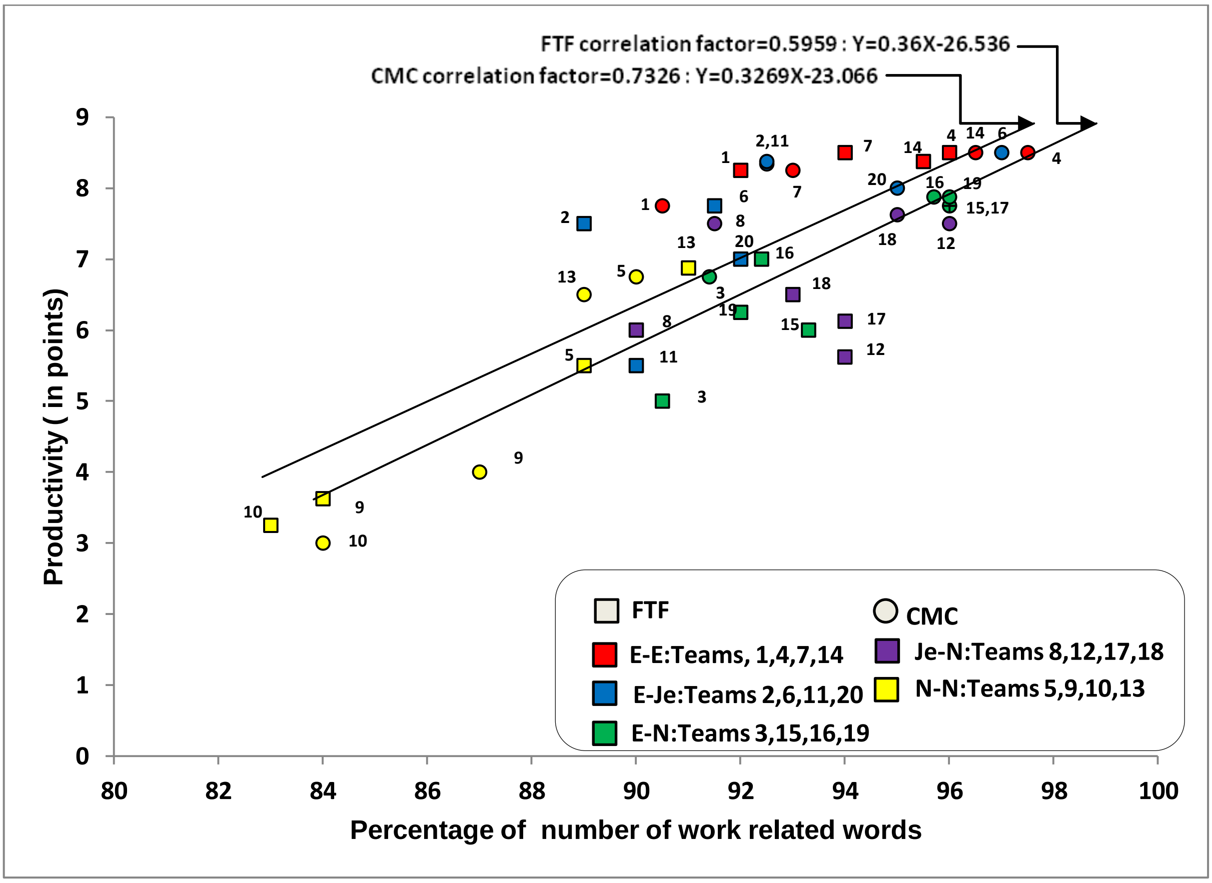


Figure 5.8: Percentages of work related words and team productivity in FTF and CMC

From Fig. 5.8, it can be observed that, there is a relationship between the percentage of work-related words and the team type. For teams type Expert-Expert, Expert-Junior expert and Expert-Novice the percentage of work related words is relatievely high. However, for teams type Junior expert-Novice and Novice-Novice with a few exceptions, the results are noticably lower. It is observed that the users in these groups spent some of their time talking about non-work related matters. It is thought that this is because, the users did not have sufficient expertise to discuss the task details in depth. This result is consistent with the work of the Ertmer & Stepich (2005) who indicated that when designers do not have a good experience they try to discuss the superficial characteristics of a problem during the design phase (see Section 2.8.1). It therefore appears that this relationship is affected by the level of expertise within the team. Generally, as pointed out in Section 4.2.2, the percentage of work-related words is higher in CMC than FTF and a careful study of Fig. 5.8 shows this leads to greater productivity.

5.4.2 Team Productivity and the Number of Exchanges

The number of exchanges has been previously defined as a measure of the collaboration between the team members while undertaking the specified task. The productivity for each team is a vital indicator for any commercial process and in a collaborative effort this can be expected to be influenced by the interaction between team members. This section therefore considers the relationship between team productivity and the number of exchanges between two users for FTF and CMC.

Figure 5.9 demonstrates the relationship between team productivity and the number of exchanges in FTF over time. It can be seen that there is a moderate positive correlation between them as indicated by the correlation factor of 0.7394. During some “time intervals” the trend of the curve is not identical to the histogram, such as for the 25 and 30 minutes time intervals, but for the others the trends are the same (i.e. productivity increases when the number of exchanges increases). For CMC, as shown in Fig. 5.10, there is also a moderate positive correlation between team productivity and the number of exchanges as indicated by the correlation factor of 0.7038.

The numbers of exchange curves have similar trends for FTF and CMC with peaks at 10 and 35 minutes. Also team productivity is higher in the same time intervals. However, in the middle section the correlation is weaker and it can be concluded that the relationship between productivity and number of exchanges with regard to time is relatively moderate.

The overall relationship (i.e. not with regard to time) between team productivity and the number of exchanges for FTF and CMC is illustrated in Fig. 5.11. The correlation factors show strong correlation for both cases, and both the slopes of the best-fit straight lines are nearly similar, this indicates the productivity is related to the number of exchanges in the same way, regardless what is the type of the communication.

As can be seen team type Expert-Expert seems to have reached a plateau in terms of productivity and the variation in the number of exchanges seems to have little effect. This presumably is due to the task being relatively easy for experts and so no matter how they collaborate, they can still achieve a high productivity a good ranking in both number of exchanges and team productivity. For the other team types, there is a positive relationship between team productivity and the number of exchanges, indicating that higher levels of collaboration lead to high productivity.

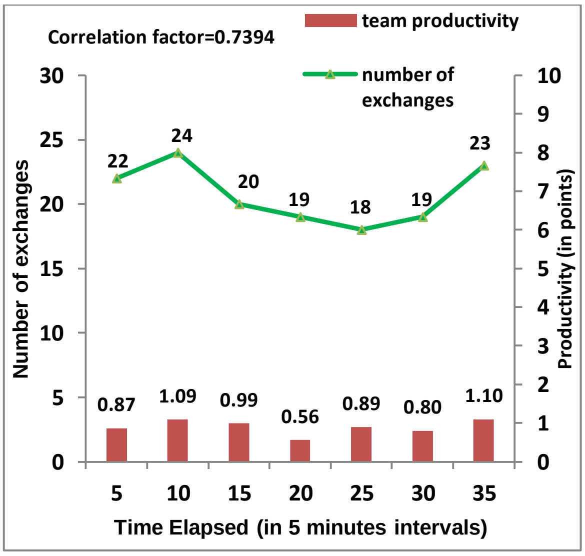


Figure 5.9: Team productivity and number of exchanges in FTF

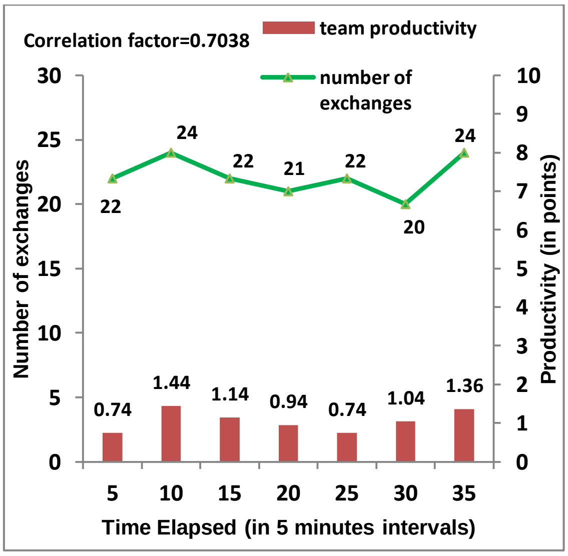


Figure 5.10: Team productivity and number of exchanges in CMC

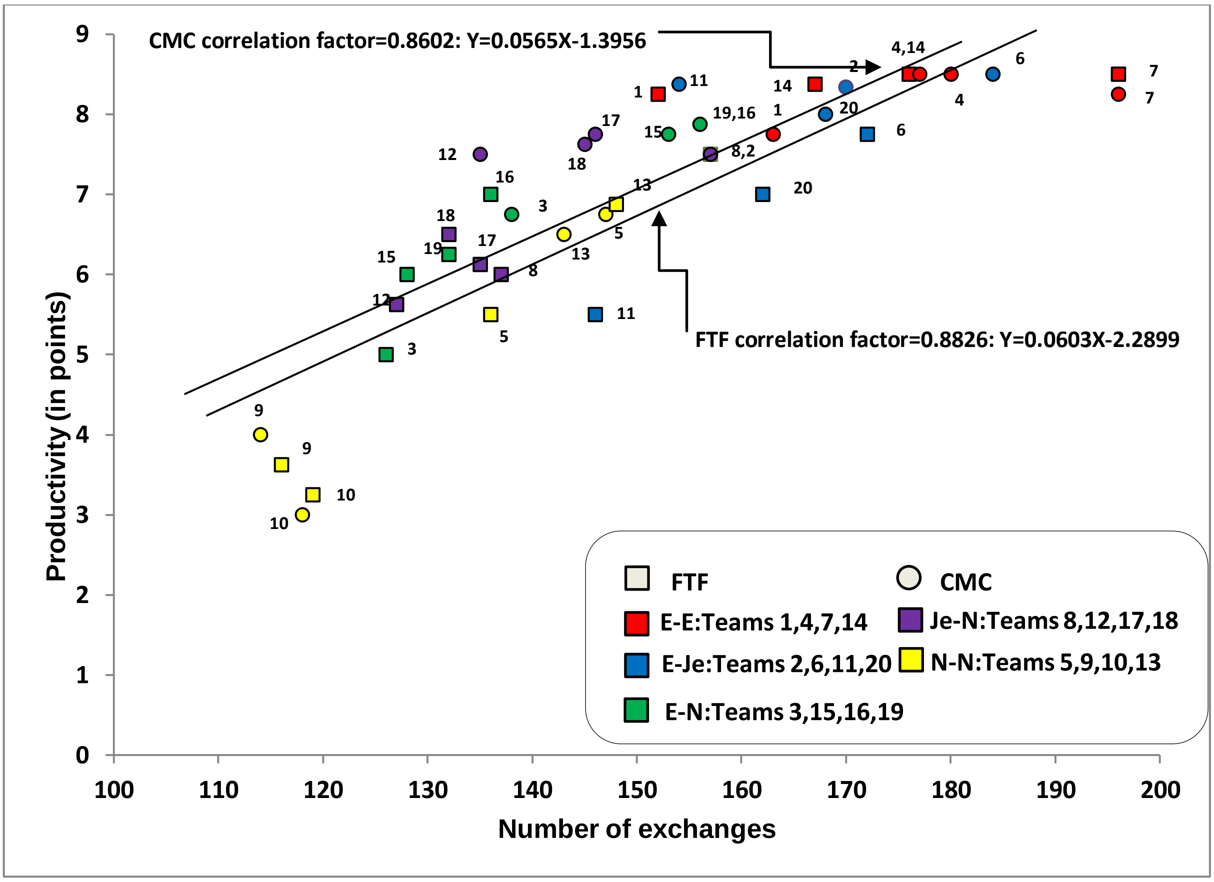


Figure 5.11: Team productivity and the number of exchanges in FTF and CMC

The number of exchanges in CMC is higher than FTF for 80% of the total experiments while the number of exchanges in FTF was higher than CMC for 15% of the total experiments, and these were equal in experiment 7 which represents 5% of the total.

5.4.3 Team Productivity and Working Time in FTF and CMC

Working time denotes the time spent by each team during the total duration of the experiment (i.e. 35 minutes) doing productive work. Working time in CMC is higher than in FTF in each time interval (see Fig. 4.10). Also, as previously stated, the total productivity in CMC is higher than for FTF.

This section examines in more detail the relationship between the working time and team productivity in each time interval. Figure 5.12 illustrates the relationship between team productivity and working time for FTF. It is clear that there is a weak positive correlation between them, as indicated by the correlation factor of 0.5357. For CMC, as shown in Fig. 5.13, it is evident that there is a strong positive correlation between team productivity and working time in each time interval, as indicated by the correlation factor of 0.8829. The comparison between the two correlation factors for both methods is interesting and it indicates that there is a fundamentally stronger focus on the task for CMC as compared to FTF.

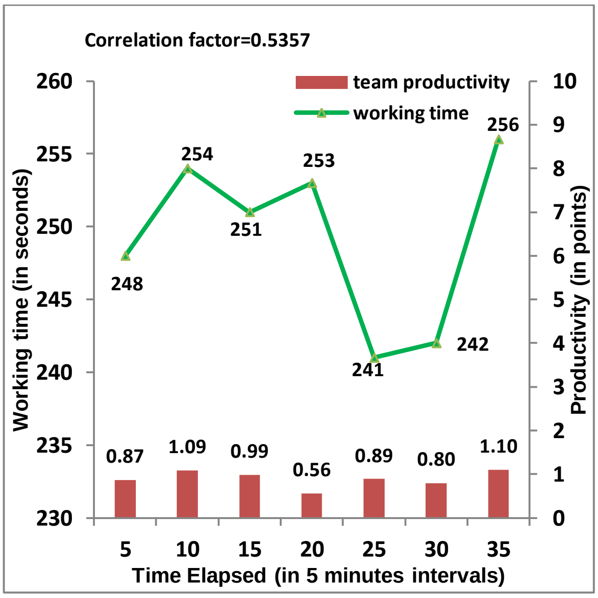


Figure 5.12: Team productivity and working time in FTF

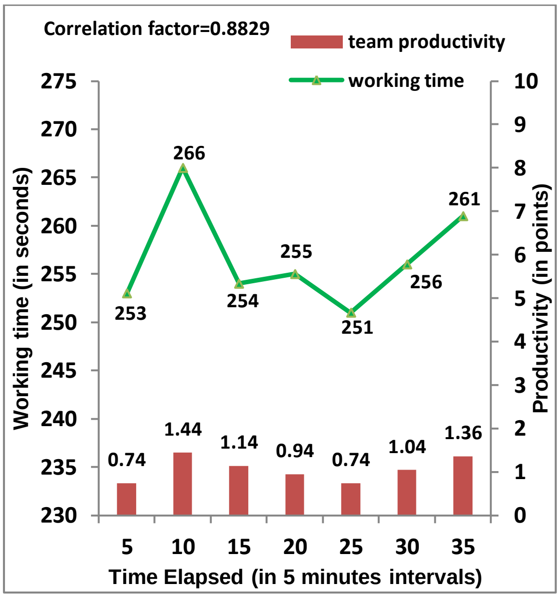


Figure 5.13: Team productivity and working time in CMC

Figure 5.14 shows the direct (i.e. not in relation to time intervals) relationship between working time and team productivity for FTF and CMC, each having 20 experiments. It is clear that generally, there is a strong positive correlation between team productivity and working time in two methods, as indicated by the correlation factors of 0.8658 for FTF and 0.8883 for CMC, also the slopes of the two best-fit straight lines are nearly equal in two cases, this means team productivity is affected by working time in same degree in both method of communication. Working time for CMC is higher than FTF in 80% of the total number of experiments.

It can be seen that team productivity increases as working time increases, as one would expect and also with the level of expertise. This consistent with the results in Fig. 5.8.

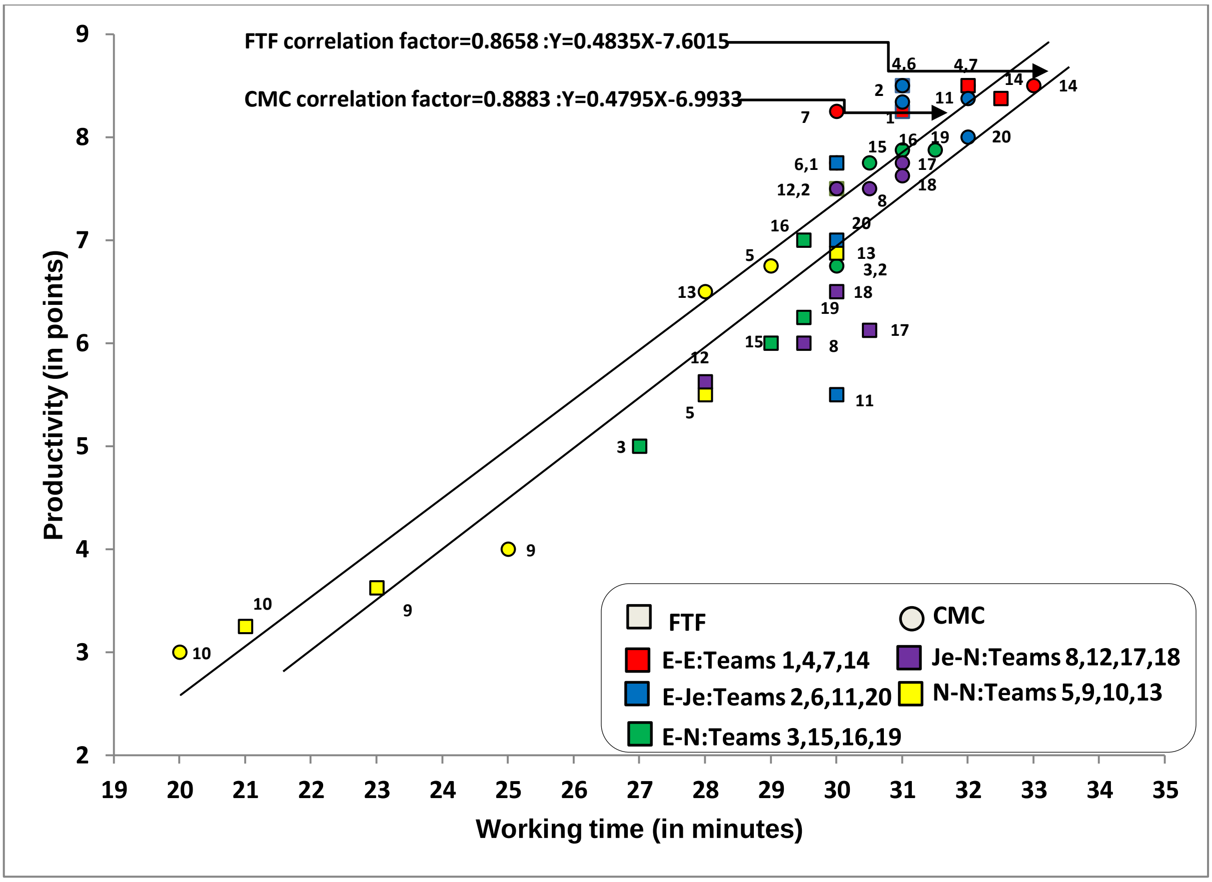


Figure 5.14: Team productivity and working time in FTF and CMC

5.4.4 Team Productivity and Wasted Time in FTF and CMC

Wasted time is defined here as the time the users spent on non-work-related activities (as detected from their speech) and for pauses which occurred during the task. The wasted time for FTF is higher than CMC in each time interval (see Fig. 4.13).

This section examines the relationship between wasted time and team productivity with respect to time. For FTF, Fig. 5.15 shows the relationship between team productivity and wasted time. It can be seen that there is a negative moderate correlation, as indicated by the correlation factor of -0.6126. Most of the wasted time occurs in the second part of the experiment.

For CMC, as can be seen in Fig. 5.16, there is a strong negative correlation between the two aspects, as indicated by the correlation factor of -0.8454. This value of the correlation factor shows that in spite of the wasted time in CMC being lower than FTF, productivity has a relationship with wasted time that is stronger than FTF.

Figure 5.17 shows the overall relationship between wasted time and team productivity for FTF and CMC, for each of the 20 experiments. Generally, there is a moderate negative correlation for FTF and CMC between team productivity and wasted time and this correlation in FTF stronger than CMC. The slope of the best-fit straight lines is nearly equal in FTF and CMC. This means effect of wasted time on team productivity is the same in both methods. As one would expect, if wasted time increases, team productivity decreases and vice versa. Wasted time in FTF amounts to more than the wasted time in CMC in 75% of the total number of experiments. There is also a relationship between the team type and wasted time as clearly the wasted time for team type Novice-Novice and to a lesser degree for teams type Expert-Novice and Junior expert-Novice is more than those for teams type Expert-Expert and Expert-Junior expert. Also, it is clear that Teams 9 and 10 have the greatest wasted time; this could be because these users have a prior relationship (and thus the highest number of non-work related words) and they have least experience (Novice-Novice, and the lack of knowledge/experience demotivated them for the work).

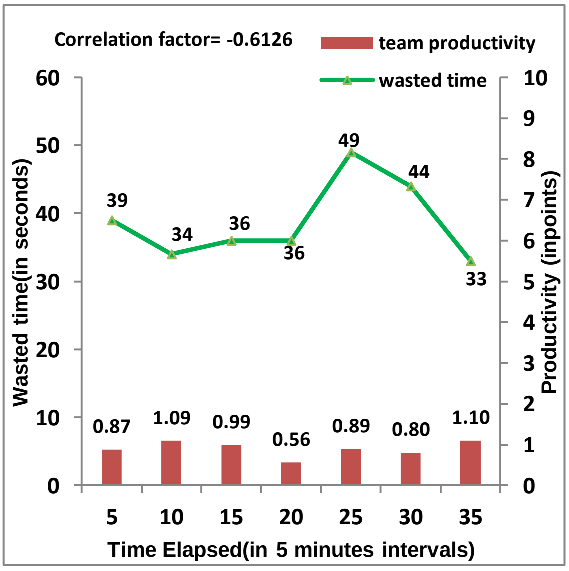


Figure 5.15: Team productivity and wasted time in FTF

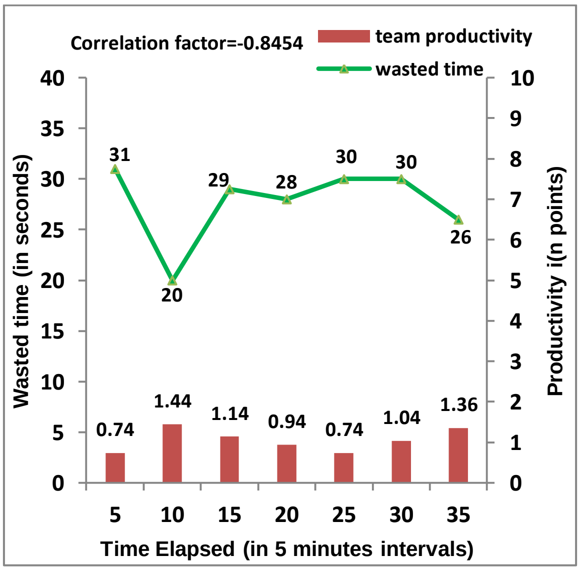


Figure 5.16: Team productivity and wasted time in CMC

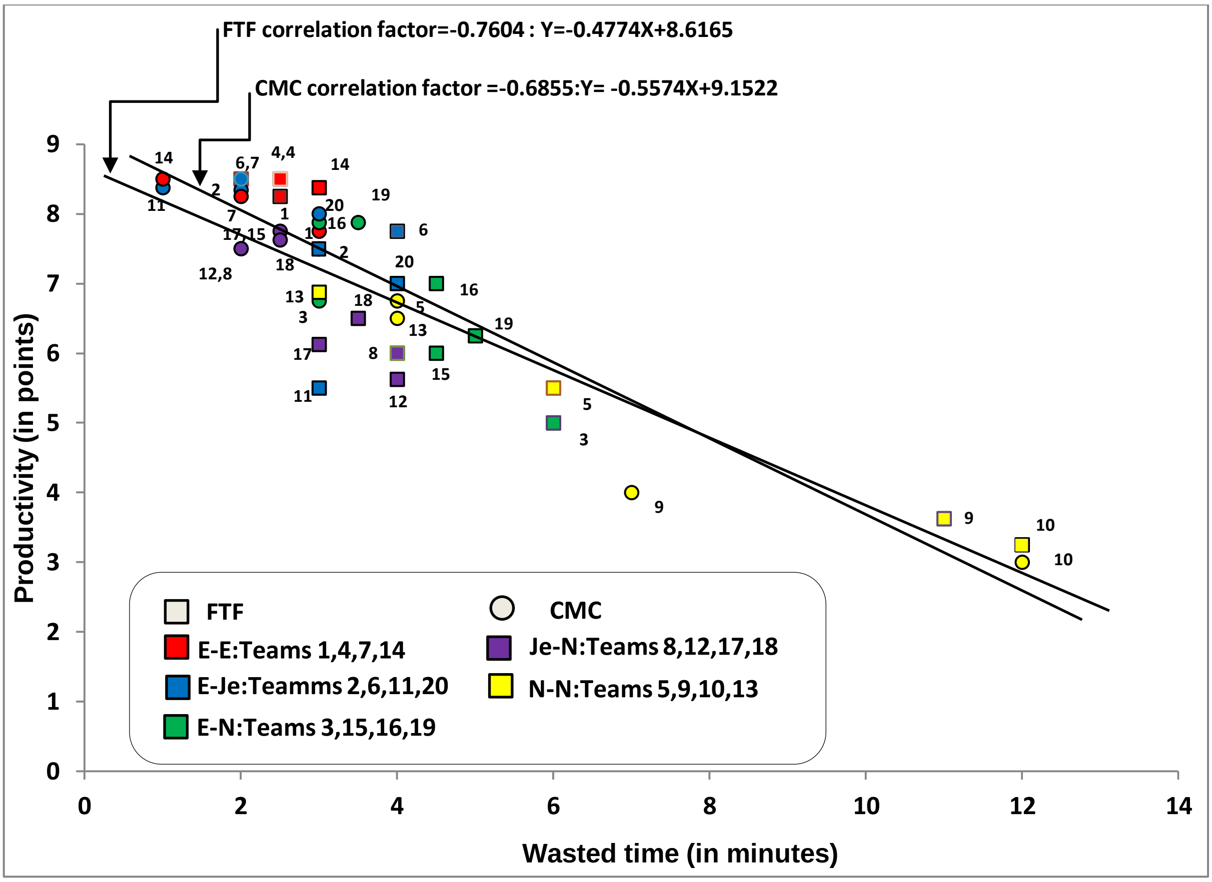


Figure 5.17: Team productivity and wasted time in FTF and CMC

5.5 Comparison between Individual and Team Productivity

Up to now, all the discussions above have been on experiments conducted on teams of two members. Further similar experiments were also conducted on individuals working on their own.

This section examines the differences between the amount of the productivity achieved by the teams and the productivity achieved by single users, working alone undertaking the same engineering design task, the single user used FTF task. This provides a useful benchmark as to how the need to communicate and collaborate with a colleague affects productivity. Nine single user experiments were conducted for each type of user (i.e. 3 Experts, 3 Juniors expert and 3 Novices). Obviously, this type of experiment, only one person is required to use the computer and the documentation giving to each user is that used in the team experiments for FTF (see Section 3.3.1). The user is given the same time, 35 minutes to finish the task and the average productivity for each type of user is shown in Table 5.3.

Table 5.3: Average of individual productivity for users according to their level of expertise

User's type	Average productivity in (points)
Expert	7.50
Junior-expert	5.80
Novice	4.00

Figure 5.18 shows the relationship between the average amount of productivity in points for the teams and single user on the vertical axis with the type team or user on the horizontal axis. The horizontal axis consists of two axes a primary axis (i.e. the lower axis) representing the type of team i.e. Expert-Expert, Expert-Junior expert, Expert-Novice, Junior expert-Novice and Novice-Novice, which have been given the numbers 4, 3, 2, 1and 0 respectively. The secondary axis (i.e. the upper axis) represents the single user's expertise such as Novice, Junior expert and Expert which have been given the numbers 0, 2 and 4 respectively.

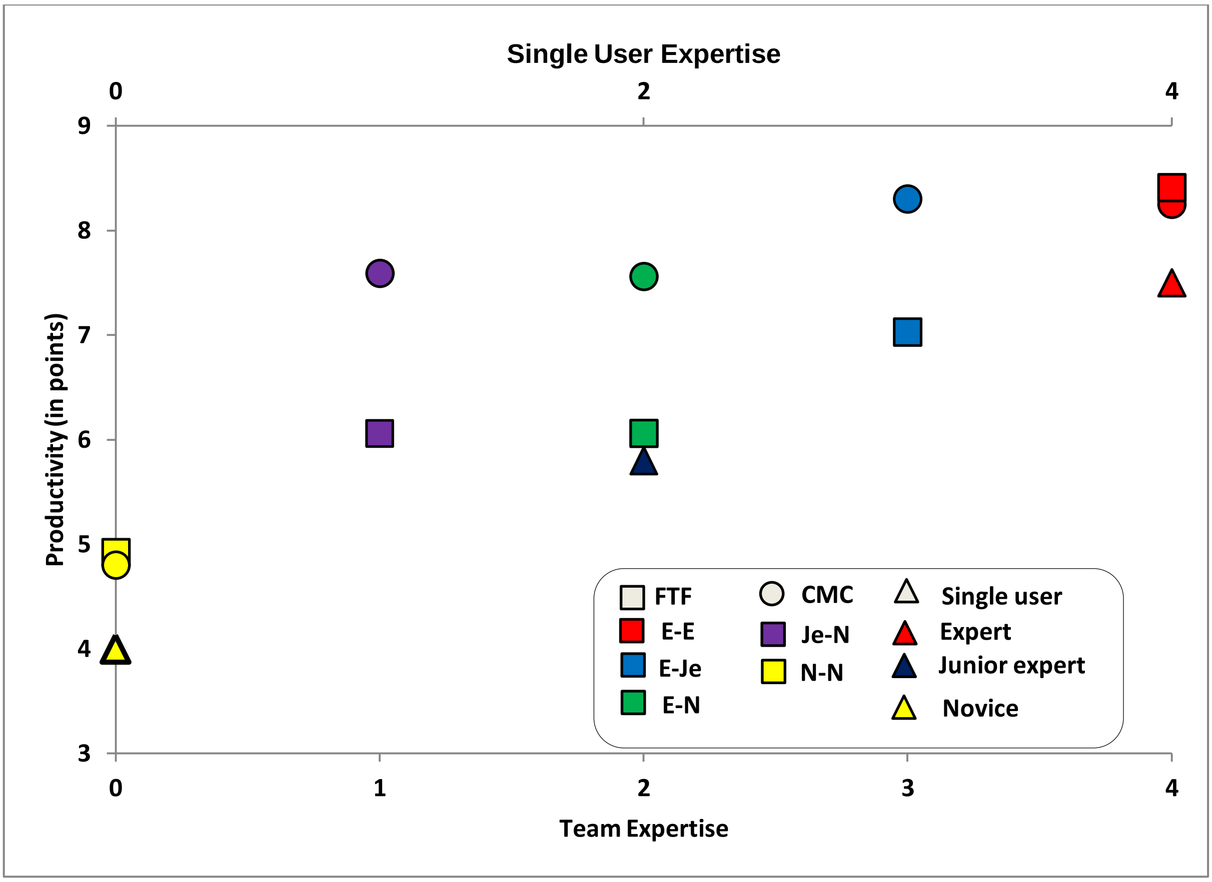


Figure 5.18: Average productivity for team and single user expertise

Figure 5.18 shows as mentioned above the pattern of correlation between productivity and expertise already seen in teams is also seen for individual workers – there is a consistency in the data seen Fig. 5.18 even though it is actually built up from superimposing two different horizontal axes. This firstly provides support for validity of the way Fig. 5.18 is composed. However, it can also be noted in Fig. 5.18 that the average team productivity (both FTF and CMC) is higher than the equivalent individual productivity is all cases; the advantage of a co-worker clearly outweighs the disadvantages of team building and communication overhead, even for such short timed-limited tasks. Table 5.4 shows the time divisions (i.e. wasted, non-specific and working) for single user and for the team respectively, through a careful analysis of the video recording of each experiment. This breakdown shows how the individual productivity comes out lower than for the equivalent team. In all cases, the working time higher or significantly higher in the team than it is in the individual. The wasted time (and the non-specific time, which further analysis has indicated to be aligned to wasted Time) are conversely also higher in the individual than for the team.

Table 5.4: Nature of time type spent by teams and equivalent single user

User type (*italics* = Team)	Wasted time (mins)		Non-specific time (mins)		Working time (mins)	
	FTF	CMC	FTF	CMC	FTF	CMC
Novice	12.0		3.0		20.0	
Novice-Novice	*8.0*	*6.75*	*1.44*	*2.25*	*25.56*	*26.00*
Junior Expert	5.5		2.0		27.5	
Expert-Novice	*5.0*	*3.0*	*1.25*	*1.25*	*28.75*	*30.75*
Expert	3.0		3.0		29.0	
Expert-Expert	*2.5*	*2.13*	*0.87*	*1.62*	*31.63*	*31.25*

Table 5.5: Comparison of individual to team ratios

Ratio of equivalent Individual to Team	Novice vs. N-N	Expert vs. E-E
Working Time	0.83	0.93
Productivity	0.81	0.90

The value of breaking down the nature of time spent is seen in Table 5.5 where average values have been used to compare the individual: team ratio for both working time (input) and productivity (output) for the novices and the experts. (An averaging of FTF and CMC values have been used to produce the team values). There is a (perhaps surprisingly) close correlation between the amount of time spent working, and the resultant productivity, e.g. the novice lone worker works 83% of the time spent working by the novice team, and the novice lone worker achieves 81% of the productivity achieved by the novice team. This same ratio pattern is also seen with the experts, although the lone expert spends more time working. It is thus clear that the reduced productivity when the individual works alone is largely due to not spending time working. This could be an issue of motivation or ability, but it would seem that whatever are the underlying reasons, the working as a team (whether it is FTF or CMC) is able to overcome these difficulties.

It was noted that generally the single user wasted time in two main ways. Firstly, the lone user asked comparatively more questions (see Section 3.3.1). Secondly, there were considerable pauses in the single user, where, at various times, the task documentation was studied at length. (In contrast, where questions are asked in the team users, these mostly were technical Revit questions).

5.6 Summary

This chapter studies and compares the difference between productivity achieved by teams using FTF and CMC and illustrates the important factors which affect productivity and explains the relationship between productivity and quantities such as words, time and number of exchanges. In addition, it compares individual productivity and team productivity. The results showed the following points.

1. Team productivity in CMC is higher than team productivity in FTF in most of the experiments and the productivity for the teams with expert users is better than for the teams containing less experienced users (i.e. productivity increases with the expertise of the users).
2. Many factors affect team productivity but, the level of expertise is the main factor. Another factor is the impact of the emotions which has been expressed as the difference between positive and negative emotions. This is a secondary factor affecting productivity. The emotions have been divided into three categories: positive emotion was positively correlated with productivity, while negative emotion was negatively correlated with productivity. Neutral emotion, however, had no relationship with team productivity.
3. There is a relationship between quantity of communication in terms of work related words and team productivity, when this number increases, productivity increases and vice versa. Additionally, team productivity has a connection with this communication in each time interval. This relationship between productivity and work-related words in CMC is higher than FTF.
4. In general, there is a strong relationship between the degree of collaboration which is represented by the main indicator (i.e. number of exchanges) and team productivity for FTF and CMC.
5. For working time, as one would expect, there is a strong positive relationship with team productivity and there is a negative relationship between wasted time and team productivity.

6. Productivity made by the team is higher than productivity made by single user for the same task. One would not expect to find this, and these results prove that the productivity has improved by team more than a single user.

In summary, Fig. 5.19 shows the relationship between team productivity and factors related to the team productivity.

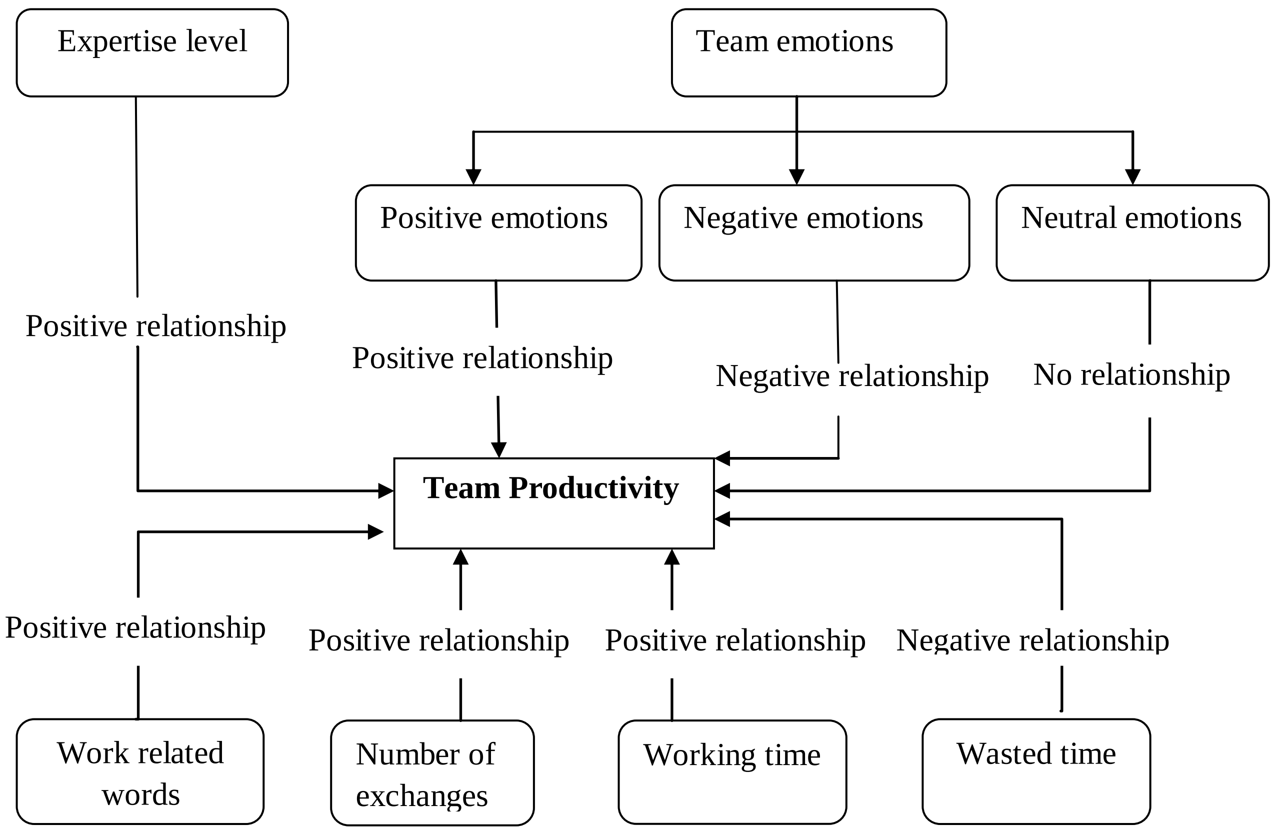


Figure 5.19: Team productivity relationships

Chapter 6

Degree of Collaboration in FTF and CMC

6.1 Introduction

This chapter deal with the degree of collaboration between team members when undertaking an engineering design task in FTF and CMC. The degree of collaboration is the interaction between users which is necessary in order for them to achieve their goals. The chapter is divided into two sections, as follows:-

1. Sections 6.2 and 6.3 examine the four main potential indicators for the degree of collaboration considered in this work. The sections examine which factor is most suitable to be chosen the primary indicator, as well as examining the potential of the other factors.
2. Section 6.4 studies the impact on the degree of collaboration by factors such as the teams' level of expertise, and emotional profiles (i.e. positive, negative and neutral).

6.2 Degree of Collaboration Indicators

This section studies the potential measures for the degree of collaboration between the users within the teams in FTF and CMC. Assessing the degree of collaboration between team members has proved to be challenging since there is no single widely agreed standards or definitions (see Section 2.9). Instead, there are many indicators that can provide a good measure for collaboration. In this research four indicators have been studied for the degree of collaboration as shown below. These include:-

- The number of exchanges which shows the amount of interaction and participation in the speech; a high number of exchanges shows a good degree of collaboration between the participants.
- Differences in individual productivities, as a ratio of the total team productivity is also regarded as an indicator for the degree of collaboration. It is argued that where there is good collaboration, then each team member would account for half the productivity of the team (i.e. zero difference in individual productivities), and hence a ratio close to zero would be an indication of good degree of collaboration between the users.

- Differences in the word count between the two users, out of the total number of words. This is regarded as another indicator of the degree of collaboration, which is similar to the differences in individual productivity. If each user speaks half of the total number of words, this indicates that there is not a domineering partner.
- Differences in the working time between the two users, out of the total working time of the team, is also regarded as an indicator for the degree of collaboration. If each user accounts for half the team's working time, then both users are collaborating and working equally, and thus a low ratio would be an indicator of a good degree of collaboration.

6.2.1 Number of Exchanges

It is clear that, at one extreme, if there is no collaboration between the users in a team, then no communication at all can be expected, or there is monologue from the dominant user, with the other user taking no part at all, both resulting in a zero number of exchanges. In contrast, if there is genuine collaboration, then a high number of exchanges can be expected. However, it is recognised that there must be an upper limit beyond which each speech transaction would be so fragmented so as to be of no or little use. The number of exchanges for FTF and CMC for each of the 20 teams of users is presented in Fig. 6.1. Here, it can be seen that for 16 of the 20 experiments, the number of exchange is higher for CMC than for FTF. These results in an overall average of 145 exchanges for FTF compared to 155 for CMC. Hence, there is a good indication of a higher degree of collaboration in CMC.

Figure 6.1 is also plotted with teams of similar expertise being grouped together. It is notable that the teams with the higher expertise have a greater number of exchanges. Furthermore, it is the teams with uneven expertise pairings such as Expert-Novice and Junior expert-Novice that consistently have a higher number of exchanges in CMC than in FTF. To a lesser extent, this is also true for the teams classified as Expert-Junior expert, even though the size of the difference is less.

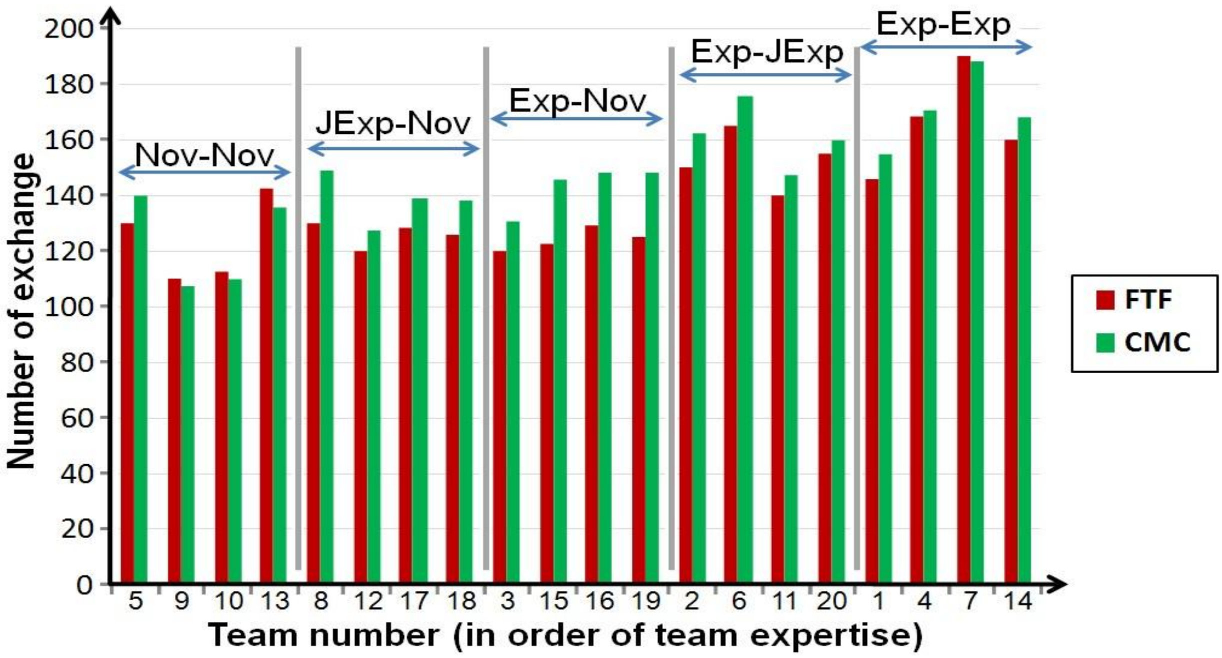


Figure 6.1: The number of exchanges for FTF and CMC

However, when the data is re-examined according to team-expertise, there is little change in productivity for the Expert-Expert teams, despite a variation in the number of exchanges from 152 to 196 (see Fig 5.11). It is an observed trend that the Expert-Expert teams are relatively uninfluenced by the varying factors (including the number of exchanges) and continue to produce high productivity regardless. However, once these four teams are removed from the calculation, there is evidently an even stronger correlation between productivity and the number of exchanges, as seen by a tighter banding of the remaining data around a best-fit straight line.

6.2.2 Individual Productivity Compared to Team Productivity

The second indicator chosen for the degree of collaboration is the difference between the productivity of the two individuals in a team, here expressed as a percentage ***P*** = | (User1 productivity-User2 productivity)| *100 % / (Team productivity). It is argued that when a team is collaborating effectively, then each member would contribute well to the productivity of the team, and thus the difference between the individual productivity would be low. Table 6.1 gives this percentage value for all 20 teams in FTF and CMC. The results show that ***P*** in CMC is lower than in FTF in 75% of the total experiments. Again this suggests that the degree of collaboration for CMC is better than for FTF.

Table 6.1: Percentage difference ***P*** between the individual productivity in FTF and CMC

Team Number	***P* for FTF (%)**	***P* for CMC (%)**
1	14.70	17.60
2	31.00	15.30
3	37.56	10.00
4	5.00	2.00
5	9.80	6.00
6	25.80	0.00
7	1.00	0.00
8	20.00	10.00
9	22.11	30.00
10	18.75	23.90
11	24.00	12.00
12	14.00	11.55
13	6.00	7.75
14	4.00	0.00
15	27.50	13.00
16	19.60	11.00
17	14.00	7.00
18	15.00	7.75
19	21.88	9.00
20	10.00	20.00
Mean average	**17.09**	**10.73**

Table 6.1 illustrates an interesting point relating to the differences in the ***P*** averages in FTF and CMC for each type of teams. For example, the team type Expert-Expert consists of teams 1, 4, 7 and 14, and the average ***P*** for these teams is 6.18 and 4.90, for FTF and CMC respectively, i.e. only a small difference of 1.28.

Table 6.2 shows the same differences in averages of ***P*** values for the other team types. It is clear that the difference values for team types Expert-Expert and Novice-Novice are significantly less than with other types of teams (with pairings of unequal expertise). Clearly, where the team is homogenous as regards to the expertise, the differences in ***P*** are low when compared with the other teams with different expertise levels. This finding in Table 6.2 is consistent with the results in Figure 6.1, which shows that the differences in the number of exchanges between FTF and CMC in teams with users of the same expertise level is also less than with the other types of team.

Table 6.2: Differences in averages of ***P*** values in individual productivity for teams in FTF and CMC

Team type	*P* for FTF (%)	*P* for CMC (%)	Difference
Expert-Expert	6.18	4.90	1.28
Expert-Junior expert	22.70	11.83	10.87
Expert-Novice	26.64	10.75	15.89
Junior expert-Novice	15.75	9.08	6.67
Novice-Novice	14.17	16.92	2.75

6.2.3 Individual Word Count Compared to Team Word Count

The third indicator for the degree of collaboration between team members is the ratio of the difference between the numbers of words spoken by the individuals in a team to the total word count of the team; this indicates the equality of participation of each member within the team. The amount of this participation depends on the nature and type of user which mainly relates to the user's behaviour when achieving the task. The equitable distribution of the speech between the users gives a clear indication about the collaboration degree between users during the experiment. If this percentage is very small, it indicates good collaboration. This percentage has been calculated as ***W*** = | (User1 word count-User2 word count)| *100 % / (Team word count).

Table 6.3 presents the ***W*** value for the 20 experiments in FTF and CMC. The results illustrate that the ***W*** value in CMC is less than FTF in 80% of cases and is equal in 20% of the total experiments. These percentages indicate that the degree of collaboration in CMC is better than in FTF and the users work more freely, with the speech between them being evenly distributed.

Table 6.3: Percentage difference ***W*** between the individual number of word in FTF and CMC

Team Number	*W* for FTF (%)	*W* for CMC (%)
1	6.00	2.00
2	26.33	2.00
3	35.78	17.60
4	0.00	0.00
5	8.00	8.00
6	23.77	15.55
7	2.44	0.00
8	21.80	2.35
9	30.00	30.00
10	10.45	5.75
11	28.00	11.65
12	6.00	2.00
13	6.00	6.00
14	4.48	2.00
15	21.80	13.90
16	24.00	12.00
17	10.45	6.38
18	12.00	6.00
19	14.00	5.75
20	30.00	11.90
Mean average	**16.01**	**8.13**

Table 6.4 illustrates the differences in averages in the ***W*** values which have been calculated for each team type in FTF and CMC. Again, ***W*** values for team type Expert-Expert and Novice-Novice are less than the other team types with unequal expertise pairing. Clearly, these results are consistent with those in Fig. 6.1 and Section 6.2.2.

Table 6.4: Differences in averages of ***W*** values in individual number of words for teams in FTF and CMC

Team type	*W* for FTF (%)	*W* for CMC (%)	Difference
Expert-Expert	3.23	1.00	2.23
Expert-Junior expert	27.03	10.28	16.75
Expert-Novice	23.90	12.32	11.58
Junior expert-Novice	12.56	4.19	8.37
Novice-Novice	13.62	12.44	1.18

6.2.4 Individual Working Time Compared to Team Working Time

The fourth indicator for the degree of collaboration is the ratio of difference between the working times of the two individuals in a team to the total working time of the team, which is previously defined as the time spent by each user to complete his/her task. Consequently, this time has been exploited evenly between the users; this means that the degree of collaboration between them is good. However, if one user spent all the time achieving the team's productivity, it indicates that there is no collaboration between the team members and one user was dominant in the task productivity.

The percentage of individual working time can be expressed as ***T*** = | (Working time spent by User1-Working time spent by User2)| x100 % / (Team working time). If this percentage is close to zero this indicates there is good collaboration because of the working time is divided equally between the two users, but if this percentage achieves a high score, the degree of collaboration is not good.

Table 6.5 illustrates the ***T*** value for 20 experiments in FTF and CMC. Here, it is obvious that this value in CMC is less than for FTF in 75% of the total experiments. These results are exactly consistent with the ***P*** value in the percentage of individual productivity; this means there is a strong relationship between the individual productivity of any user with the working time for one particular user.

Table 6.5: Percentage difference ***T*** between the individual working time in FTF and CMC

Team Number	*T* for FTF (%)	*T* for CMC (%)
1	2.40	4.20
2	31.80	3.40
3	52.00	11.32
4	1.00	0.00
5	7.50	6.25
6	32.00	16.00
7	4.00	1.00
8	18.50	4.70
9	20.00	30.00
10	6.87	10.00
11	32.85	4.00
12	3.80	0.00
13	5.25	6.00
14	2.00	1.45
15	23.00	15.00
16	18.75	10.15
17	8.50	7.00
18	7.15	5.00
19	15.38	10.60
20	18.15	25.20
Mean average	**15.55**	**8.57**

Table 6.6 shows differences in averages of ***T*** values in individual working time for each team type in FTF and CMC. It is evident that the differences in the averages for the ***T*** values for team type Expert-Expert and team type Novice-Novice are less than for the other team types. These results are also consistent with the previous results in Figure 6.1 and Sections 6.2.2 and 6.2.3.

Table 6.6: Differences in averages of ***T*** values in individual working time for teams in FTF and CMC

Team type	*T* for FTF (%)	*T* for CMC (%)	Difference
Expert-Expert	2.35	1.67	0.68
Expert-Junior expert	28.70	12.15	16.55
Expert-Novice	27.29	11.77	15.52
Junior expert-Novice	9.49	4.18	5.31
Novice-Novice	9.90	13.07	3.17

6.3 The Principle Indicator for Collaboration

The productivity for any team is the main objective of the collaboration process in this work. A good degree of collaboration is therefore expected to result in high productivity. It is necessary to have a specific measure of the degree of collaboration, so that its effect on, for example, productivity can then be assessed. Four different indicators have been postulated above, and it is necessary to assess which of these four is the best indicator. It is thus useful to separately examine the relationship between each indictor with team productivity.

Figure 5.11 gives the relationship between team productivity and number of exchanges, where there is a strong positive correlation between them for both FTF and CMC (correlation factor = 0.8826 and 0.8602 respectively).

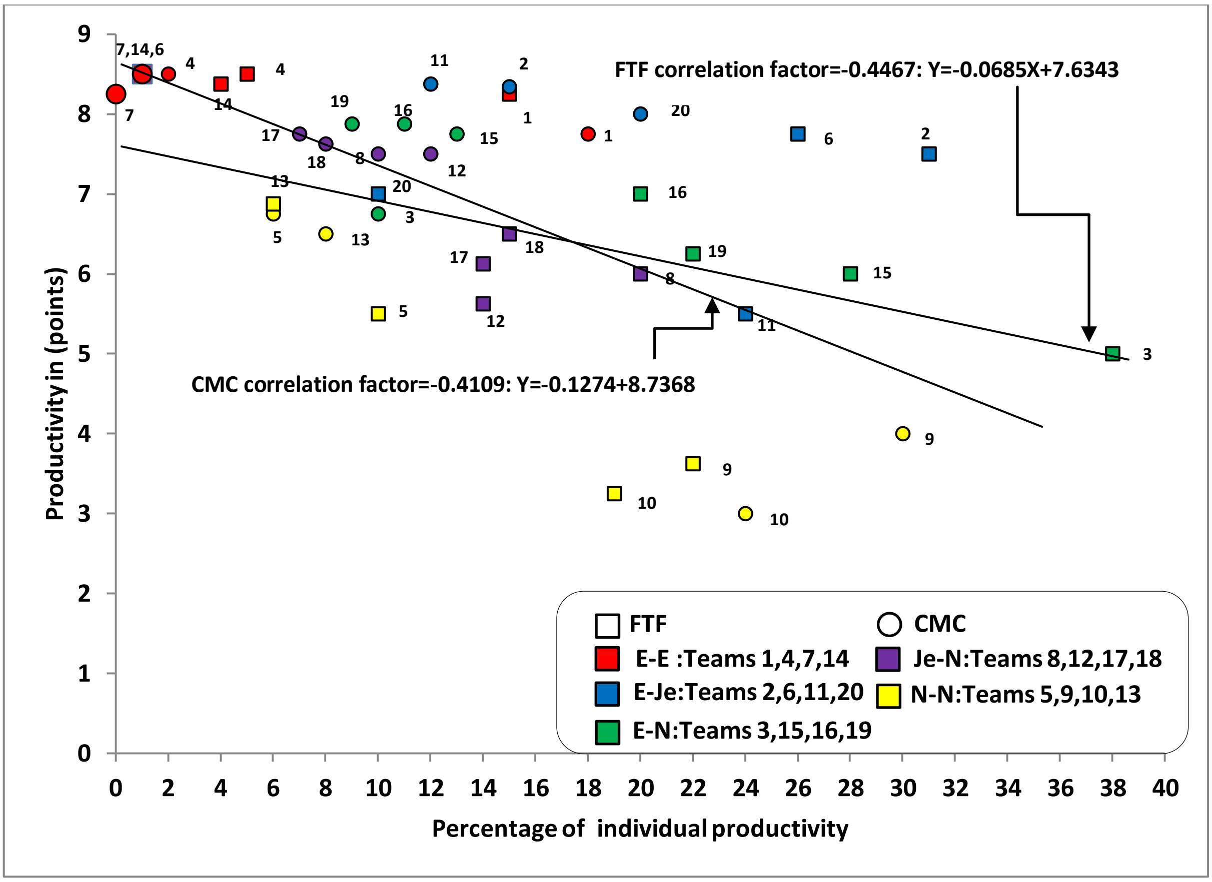


Figure 6.2: Percentage of individual productivity and team productivity in FTF and CMC

Figure 6.2 shows the relationship between percentages of individual productivity and team productivity, and there is a weak correlation for both FTF and CMC (correlation factors = -0.4467 and -0.4109 respectively).

Similarly, Figs. 6.3 and 6.4 show the same relationship between team productivity and percentage of individual words (i.e. ***W***), and percentage of individual working time (i.e. ***T***) respectively. It is clear again the correlation factors are weak for both, in ***W*** it is -0.4569 for FTF and -0.2619 for CMC. For ***T***, the correlation factors are -0.4276 for FTF and -0.3126 for CMC.

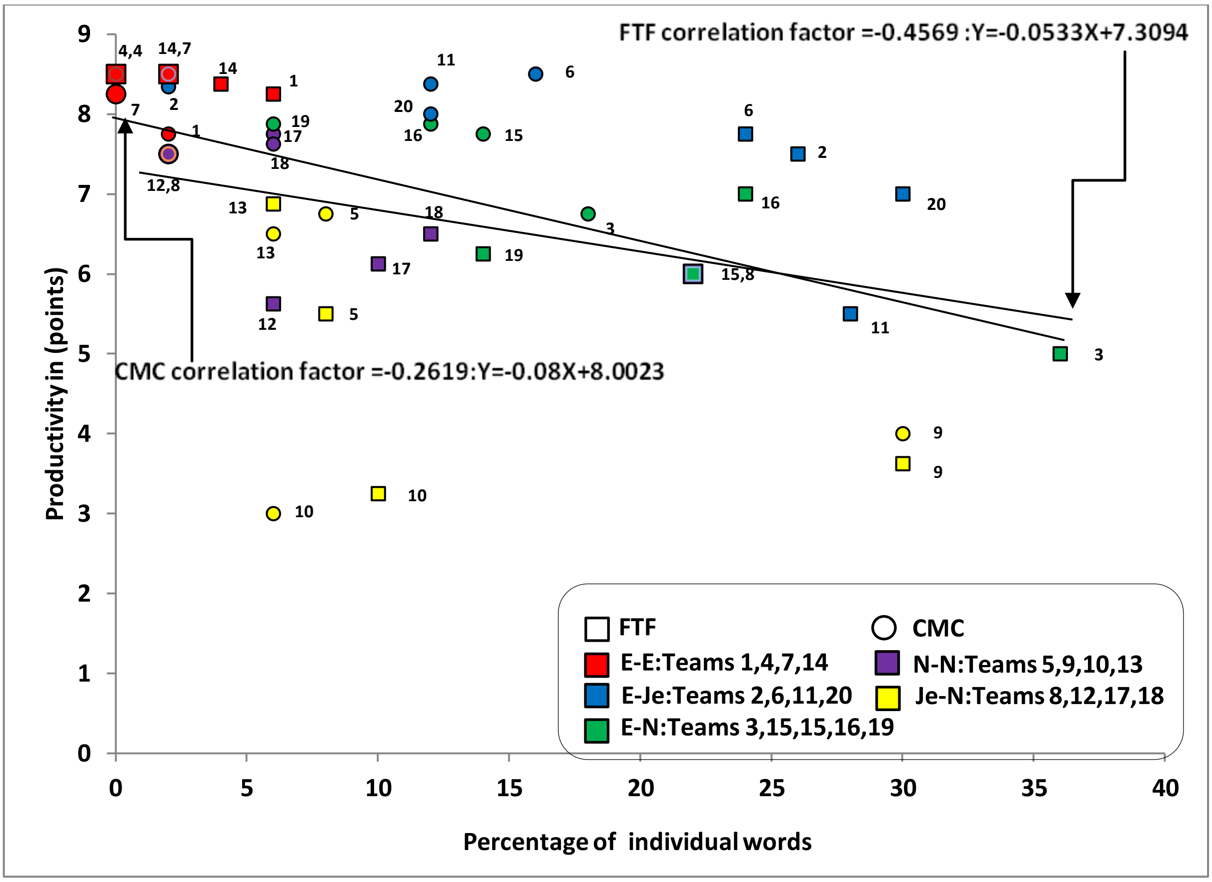


Figure 6.3: Percentage of individual words and team productivity in FTF and CMC

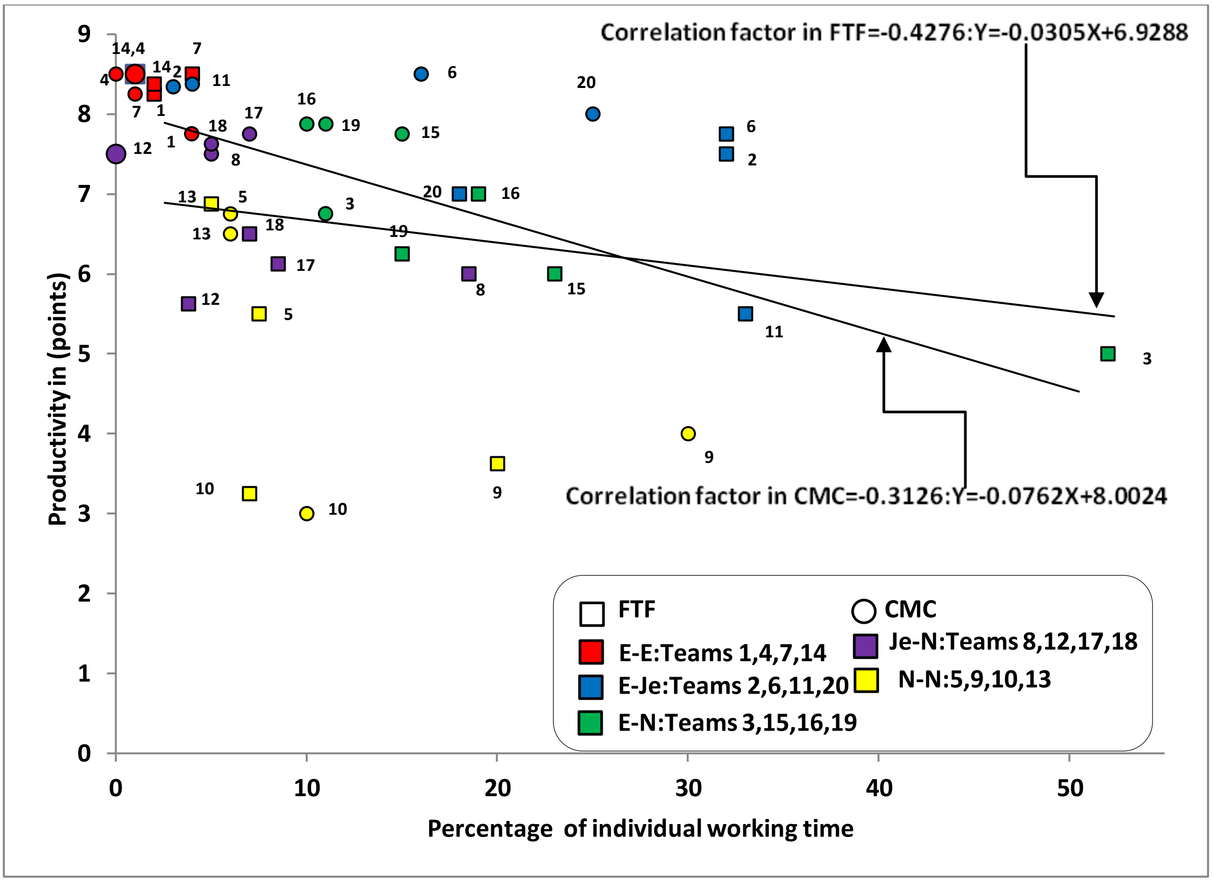


Figure 6.4: Percentage of individual working time and team productivity in FTF and CMC

Table 6.7: Correlation factors for four indicators of collaboration degree with team productivity in FTF and CMC

Correlation factors	Number of exchanges	Percentage of individual productivity (*P*)	Percentage of individual number of words (*W*)	Percentage of individual working time (*T*)
In FTF	0.8826	-0.4467	-0.4569	-0.4276
In CMC	0.8602	-0.4109	-0.2619	-0.2619

It is noted that the four indicators are different quantities; one is a summation number, and the other three percentages. The correlation factors have been deliberately calculated according to the ranked data (as opposed to raw data) in each case, which normalises the data and makes it dimensionless, and thus allow direct comparison between the four indicators. Table 6.7 shows the correlation factor for all four indicators in FTF and CMC, it is clear that the number of exchanges has much the better correlation factor with team productivity when compared to all the other indicators, by two to three times.

The number of exchanges is clearly the best indicator of degree of collaboration, and therefore it is the only indicator used for degree of collaboration in the rest of the current work.

6.4 Factors Affecting the Degree of Collaboration

The degree of collaboration is one of the important parameters in determining team performance, and this parameter is affected by several factors which may work to reduce or increase this indicator. Here, it is beneficial to study effect of these factors on degree of collaboration which is represented by the main indicator (i.e. number of exchanges), such as the level of expertise and the total emotional profile.

6.4.1 Expertise Level

Figure 6.5 shows the relationship between the degree of collaboration in terms of the number of exchanges and the expertise level for the teams in FTF and CMC. Here, it is evident that there is a moderate positive correlation between them in FTF and strong correlation in CMC, as indicated in the correlation factor of 0.7208 and 0.8476 respectively. Both the slopes of two best-fit straight lines are nearly the same for FTF and CMC; this indicates the number of exchanges in both methods is affected in the same degree by expertise level.

Generally, the team expertise seems to be the important factor for exchanging speech between the users within the team, this result is in accordance with the work of Jain (2010) who argued that team expertise helps team members to collaborate, coordinate and share information to obtain new innovations (see Section 2.8.1). (Although the number of exchanges has been calculated according to “total words”, and not only “work-related words”, these two word counts have actually been nearly the same for all teams and team-types, i.e. “non work-related words” have been typically only a very small percentage). The teams with a high level of expertise have a high number of exchanges (i.e. good degree of collaboration), but the other teams with lower expertise have smaller number of exchanges. This is clear in Fig. 6.5 where the sum of the actual number of years of experience for each team (and not just the team-type) have been plotted with the number of exchanges.

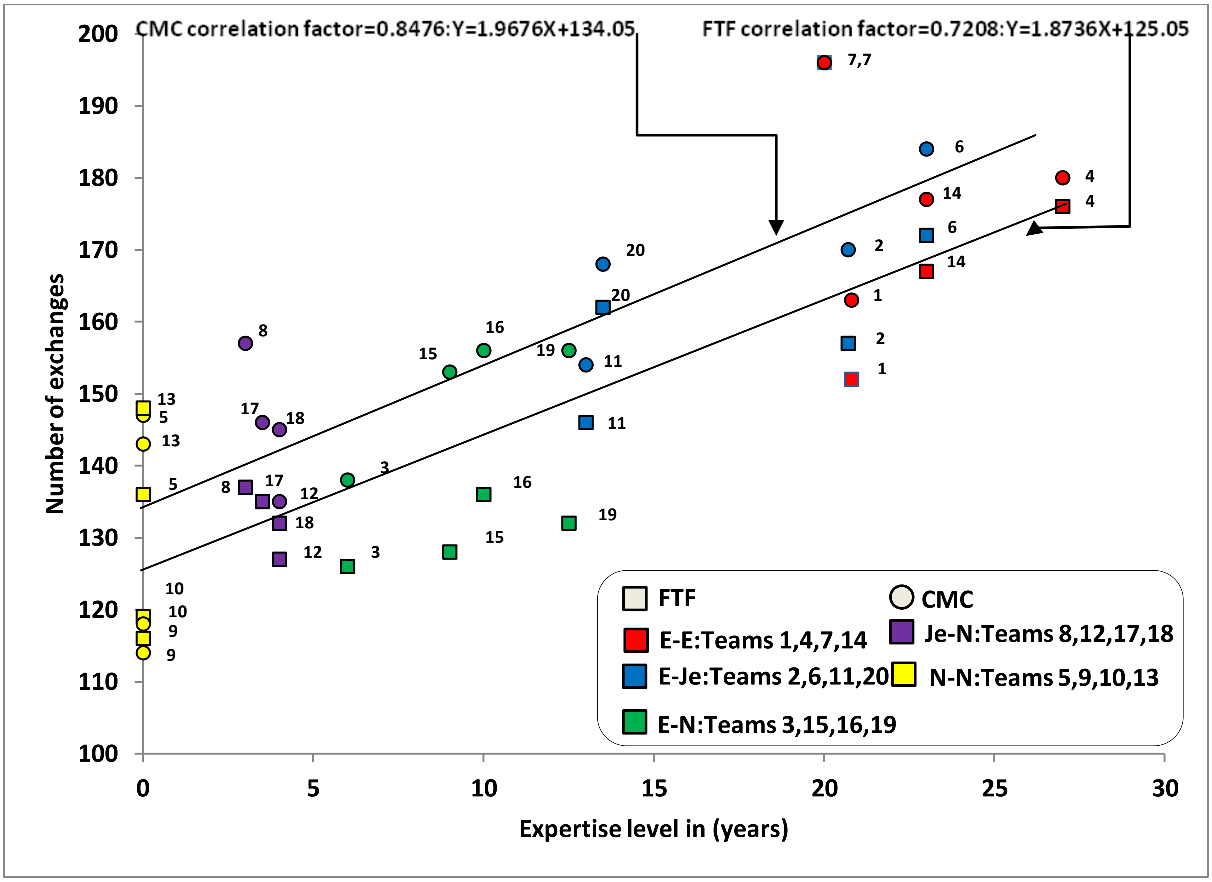


Figure 6.5: Number of exchanges and teams' expertise levels in FTF and CMC

6.4.2 Emotional Profile

This section clarifies the relationship between the emotional categories for the teams with the number of exchanges. As established in Section 5.3.1, the emotional factor is one of the important factors after the level of expertise, and has big effect on the team productivity in FTF and CMC. Collaboration between team members depends basically on the behaviour of each member during the work and this behaviour has a strong effect on team effectiveness across different task environments (Ellis et al, 2005). To determine the effect of this factor on the degree of collaboration, it is therefore useful to examine the relationship between each type of emotion separately.

6.4.2.1 Total Positive Emotions

Figure 6.6 demonstrates the relationship between the total positive emotions in the teams and the number of exchanges in FTF and CMC. In general, there is strong correlation between the positive emotions and the number of exchanges in CMC while the correlation is moderate in FTF, as indicated in the correlation factors of 0.8812 and 0.7609 respectively. The slope of the best-fit straight line for CMC is slightly higher than FTF; this means the number of exchanges is more related with total positive emotion in the CMC method. Positive emotions create a positive atmosphere within the team members, for example, cooperative emotion increases the interaction between the users whenever one or two of the users are cooperative and this means that the number of exchanges should increase. Confidence (rather than hesitation) and respect for the other member within the team make collaboration between the users more active, which would seem to lead to an increase in the number of exchanges and so on.

It is clear that the teams with expert users have a good score in positive emotions and this engenders a good environment for collaboration and an increase in the number of exchanges. Consequently, this reflects negatively with a team that has a bad score in positive emotions.

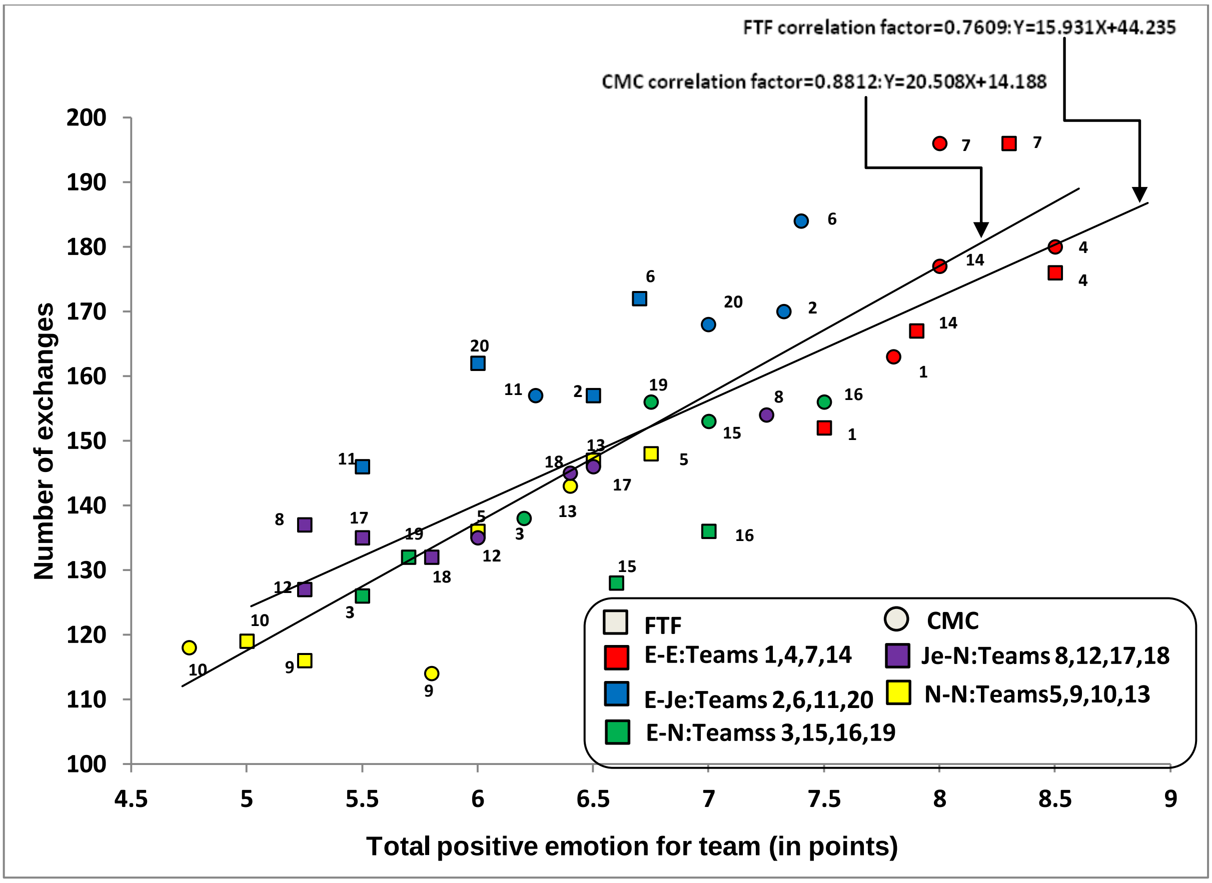


Figure 6.6: Number of exchanges and team's positive emotions in FTF and CMC

6.4.2.2 Total Negative Emotions

Figure 6.7 displays that there is a strong negative relationship between the negative emotions and the number of exchanges. Here, the strength of this correlation in CMC and FTF is nearly equal. Both slopes of the two best-fit straight lines have nearly the same; this means number of exchanges is effected to the same degree by negative emotions in FTF and CMC. Negative emotions such as being domineering, shy, aggressive, disappointed, etc, reduce the interaction between the team members, and hence the collaborative work diminishes and the degree of collaboration is at its lowest level. Here again, teams with an expert user have a low score from the total negative emotions and a high score for the number of exchanges (i.e. a good degree of collaboration). In contrast, it is clear that the teams with novice users have a high score of negative emotions, with a low score for the number of exchanges.

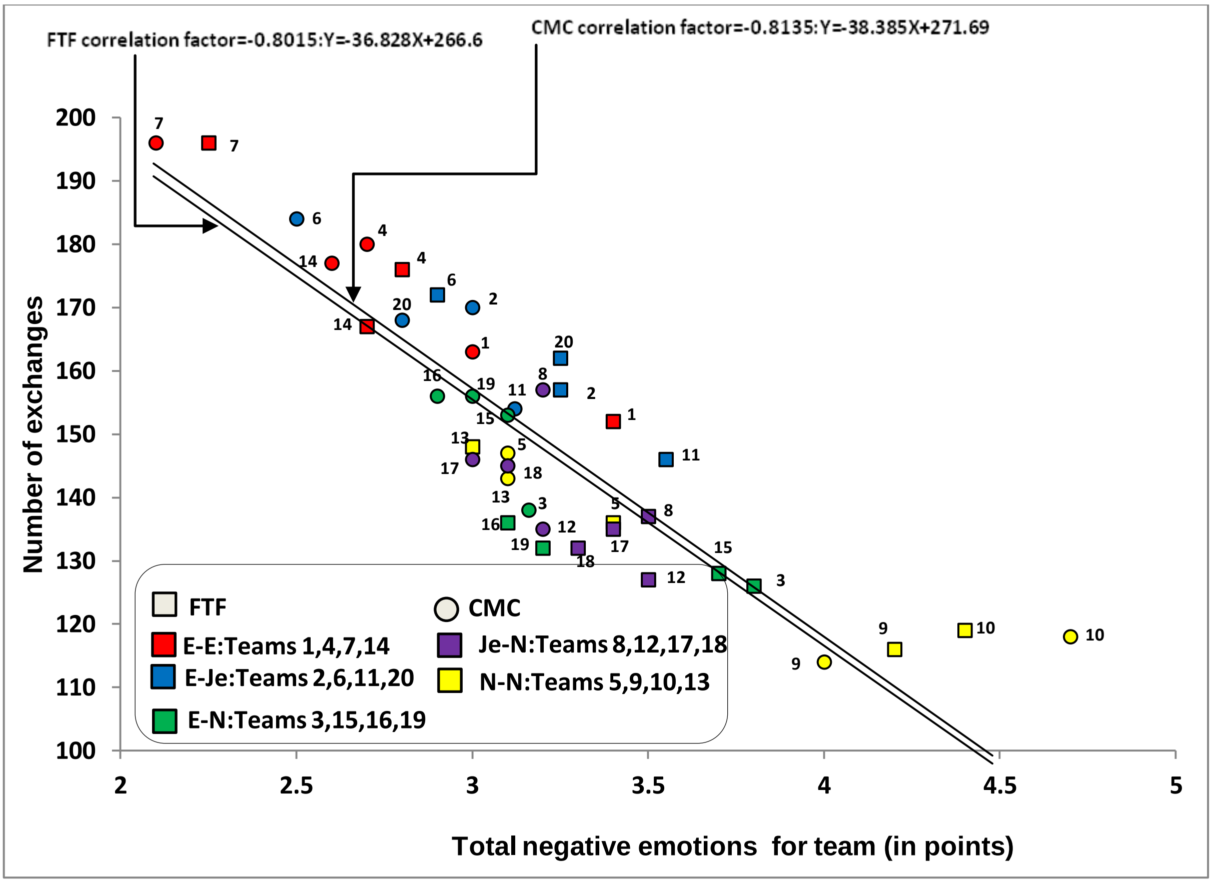


Figure 6.7: Number of exchanges and team's negative emotions in FTF and CMC

6.4.2.3 Total Neutral Emotions

Figure 6.8 shows the relationship between the number of exchanges and the total neutral emotions for the teams in FTF and CMC. It is clear that very weak correlation exists between these in FTF, as indicated in the correlation factor of 0.145, and this is nearly consistent with the relationship between team productivity and the total neutral emotions (see Section 5.3.1.3). It can be seen that this category of emotions has a weak correlation with the degree of collaboration in CMC, as indicated in the correlation factor is -0.42, and this is consistent with results in (Section 5.3.1.3) which proved there is no effective relationship between neutral emotions and team productivity. It is clear that also the slopes of two best-fit straight lines are different in each case, positive for FTF and negative for CMC.

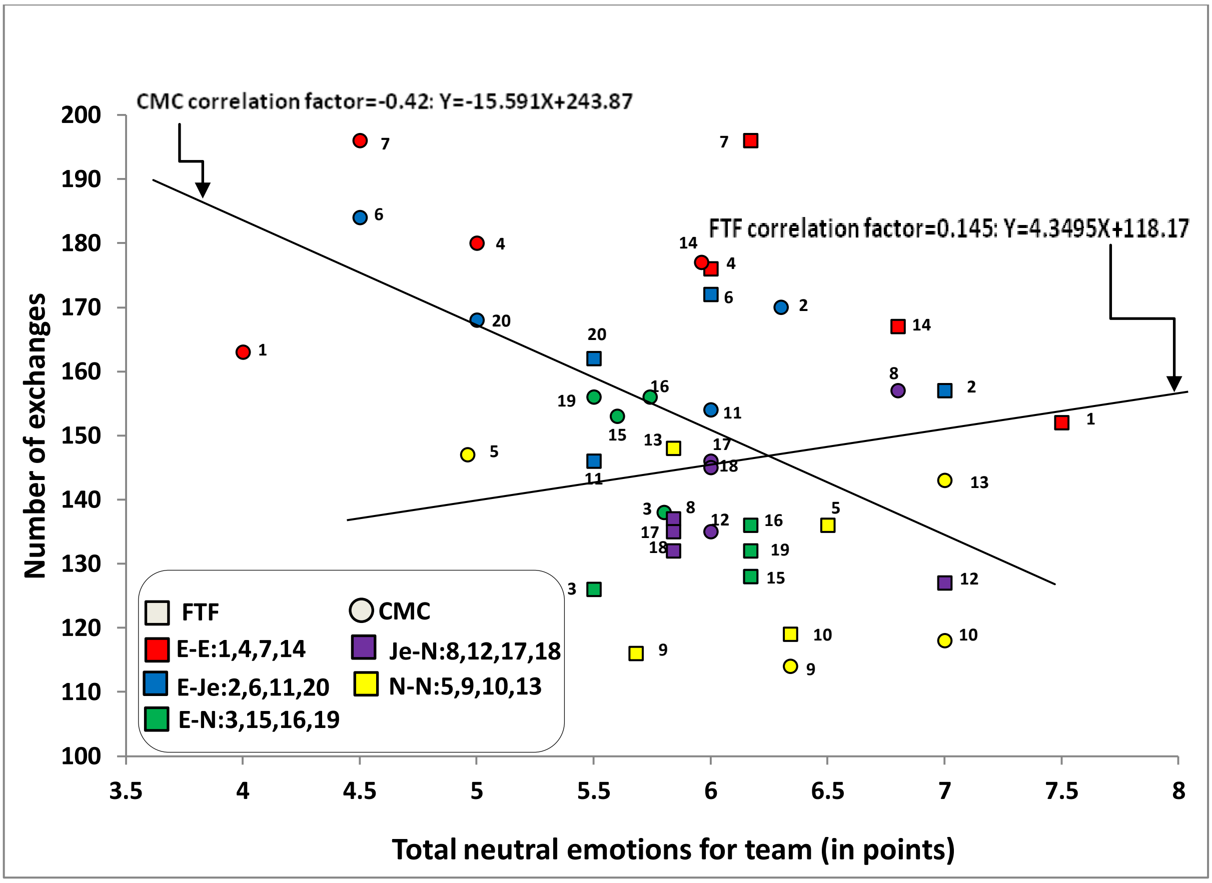


Figure 6.8: Number of exchanges and team's neutral emotions in FTF and CMC

6.5 Summary

This chapter examined the term degree of collaboration in FTF and CMC to establish the best indicator for this term. This came about because of the difficulty in finding a real scale to measure the degree of interaction and collaboration for team members when achieving a task. Additional to this, the chapter also considered the main factors influencing the degree of collaboration, as follows:-

1- There are four main indicators for the degree of collaboration: the number of exchanges is the key factor and others are secondary factors, such as the percentages of individual productivities, individual number of word count and working time.

2- The difference between the number of exchanges in FTF and CMC for the Expert-Expert and the Novice-Novice categories is less than the differences for other types, such as the Expert-Novice, Junior expert-Novice and the Expert-Junior expert (i.e. the difference between FTF and CMC in teams have the same user expertise less than the teams have users in different level of expertise).

3- The ***P*** values for individual productivities , ***W*** values for individual number of words count and ***T*** values for individual working time in CMC is less than the ***P, W*** and ***T*** values in FTF. This means that CMC has a better degree of collaboration than FTF.

4- There is a positive relationship between expertise level and degree of collaboration for FTF and CMC, and degree of collaboration is effected in same level by expertise level in both communication methods.

5- There is positive relationship between degree of collaboration and total positive emotions for the team and this relationship for CMC is better than for FTF. For the negative emotion, there is a negative relationship between number of exchanges and total negative emotions. Finally there is no relationship between degree of collaboration and total neutral emotions.

Chapter 7

Design Quality in FTF and CMC

7.1 Introduction

This chapter explains the differences in design quality between the various types of teams work when collaborating using both FTF and CMC. In spite of design quality being a very large subject which is difficult to define and too broad to treat in depth for this work, it is still useful to do some study of the subject. Therefore, an evaluation of the differences in quality of the final products (i.e. the Revet designs) from FTF and CMC has been made.

The chapter is divided into four sections as follows:

1. Section 7.2 provides details about the assessment of the existing methods for design quality calculation and which method gives the best results.
2. Section 7.3 considers the factors affecting design quality such as expertise levels and emotional profiles.
3. Section 7.4 studies the relationships between design quality and some of teams' output such as team productivity and the degree of collaboration.
4. Section 7.5 compares between team design quality and single user design quality.

7.2 Design Quality Calculations

The design quality depends on the quality of the design team's decision making during the design process. In this work, the evaluation has been on the basis of two types of requirements, according to the importance of each requirement in the design process (see Appendix D).

- The "fundamental requirements" are the basic, necessary, obvious and expected design requirements (e.g. a room must have a door; there must be stairs between two floors, etc.). Since these requirements are typically self-evident, they do not cause large disputes between the team members, and require only a small degree of negotiation. The evaluation process here is to show that the design satisfies the minimum standards of design quality, without which the evaluation cannot proceed to the second set of requirements (i.e. the usability requirements).

- In the "usability requirements", the evaluation is on further details related to the functionality and the ease of use of the design. The evaluation here is more specialized in secondary factors such as, the direction in which a door opens, the position of furniture, whether the type of element is suitable or not. It includes items such as appropriate material types and specifications (including aspects such as health and the environment), exploiting the optimum distribution for electricity fixtures, the type of handles, and so on. In this work, the "design quality" (in points) for any workset has been defined as a summation of points for the design quality for the fundamental requirements and usability requirements.

When all the worksets evaluations for design quality have been completed, the design quality for the team is given as the average of the sum for the 4 worksets for both FTF and CMC; in this way, it is possible to obtain the design quality for each team in both methods.

Table 7.1 illustrates the design quality for all the teams for FTF and CMC. There is a small difference between the average of the design quality in CMC and FTF with the average for CMC being slightly higher than for FTF. The design quality for FTF is higher than CMC in 35% of the total number of experiments and the design quality for CMC is higher than FTF in 55% of the total number of experiments, they are equal in 10% of the total number of experiments.

Table 7.1: The design quality in FTF and CMC (Maximum points is 10)

Team Number	Team Type	Design Quality in FTF(points)	Design Quality in CMC points)
1	Expert-Expert	9.00	8.00
2	Expert-Junior expert	8.50	9.00
3	Expert-Novice	5.50	6.50
4	Expert-Expert	8.50	8.00
5	Novice-Novice	5.50	5.00
6	Expert-Junior expert	9.00	9.50
7	Expert-Expert	9.00	9.50
8	Junior expert-Novice	4.50	5.00
9	Novice-Novice	3.50	3.00
10	Novice-Novice	3.50	3.00
11	Expert-Junior expert	6.00	7.50
12	Junior expert-Novice	6.00	6.50
13	Novice-Novice	6.00	6.00
14	Expert-Expert	8.50	8.00
15	Expert-Novice	6.50	7.50
16	Expert-Novice	6.50	7.50
17	Junior expert-Novice	6.50	7.00
18	Junior expert-Novice	7.00	7.50
19	Expert-Novice	8.00	7.00
20	Expert-Junior expert	6.00	6.00
Mean Average		**6.70**	**6.90**

Table 7.2 illustrates the differences between the averages of the design quality for each type of team. Generally, team type Expert-Expert has the highest score for design quality and team type Novice-Novice has the lowest score, with the other teams types ranging between them in the table. This means the design quality mainly depends on the expertise level, this result concurs with the work of Baigent (2000) who indicated that the expertise level of the designers is the most influential factor in the design quality (see Section 2.10.1). It is also clear that, the design quality for team type Expert-Expert and team type Novice-Novice for FTF is higher than CMC. For team type Expert-Expert, this is thought to be due to the teams having expert users who prefer to work in the FTF environment rather than the CMC because they are not familiar with advanced software. These results are consistent with those in Section 5.2, which discusses the relationship between team productivity and level of expertise.

For team type Novice-Novice, in spite of the differences being very small, these teams received a score for design quality in FTF that is higher than CMC. This is thought to be once again because of their lack of familiarity with collaboration software. For the other team categories, it is clear that the design quality in CMC is higher than FTF. It is assumed that is because in these types of teams, the users are more comfortable using computer software and CMC. These results consistent also with those in Section 5.2.

Table 7.2: Averages of the design quality for experiment types in FTF and CMC

Team type	Average of team design quality in FTF(points)	Standard deviation	Average of team design quality in CMC(points)	Standard deviation	Differences between design quality in FTF and CMC(points)
Expert-Expert	8.75	0.25	8.38	0.64	0.37
Expert-Junior expert	7.38	1.38	8.00	1.36	0.62
Expert-Novice	6.63	0.89	7.13	0.41	0.500
Junior expert-Novice	6.00	0.93	6.50	0.93	0.500
Novice-Novice	4.63	1.13	4.25	1.30	0.38

7.3 Factors Affecting Design Quality in FTF and CMC

This section discusses the factors affecting design quality in FTF and CMC. Two factors are studied in this section, these being level of expertise and emotional profile as follows.

7.3.1 Expertise Level

As can be seen in the previous chapters, the expertise level is, as one would expect, one of the basic factors affecting team performance (Baigent, 2000). Figure 7.1 shows the relationship between the teams' expertise (i.e. the combined expertise of User1 and User2) and the teams' design quality. The general trend of Fig. 7.1 indicates how design quality increases as team expertise increases, and vice versa, i.e. design quality depends on the accumulated expertise of the designers. The exception is the Novice-Novice teams where design quality is very variable, and hence not particularly sensitive to expertise level.

This high variability within the Novice-Novice category needs some explanation. Teams 9 and 10 have the lowest scores in design quality, which are significantly lower than the scores of even the other Novice-Novice teams (5 and 13). Team 9 consists of people with secondary school education, but with no connection with science, technology or engineering. Team 10 consists of two Chemistry PhD students. These two teams thus have no experience, but also no knowledge nor skill related anything about design. On the other hand, Teams 5 and 13 consist of PhD students in Computer Science and Civil Engineering undergraduate students in their first year. Although Teams 5 and 13 also have no experience in design, they do have some knowledge and/or skill related to design. The Computer Science students were already very familiar with use of advance CMC software, and the Civil Engineering students would have some basic understanding of the design process. In this way, while Teams 5 and 13 (with no experience) can still be meaningfully considered in Figure 7.1, Teams 9 and 10 should be treated as insignificant outliers.

It is clear that all of the Expert-Expert and many of the Expert-Junior expert, teams have a good design score quality. Conversely Junior expert-Novice teams have a lack of expertise which caused their design quality to have a lower score. Within the limits of the scope of this study (which has a limited number of participants per team, and limited number of teams), this finding should probably also not be generalized beyond the type of task actually tested, which is that of team conceptual design in the construction industry.

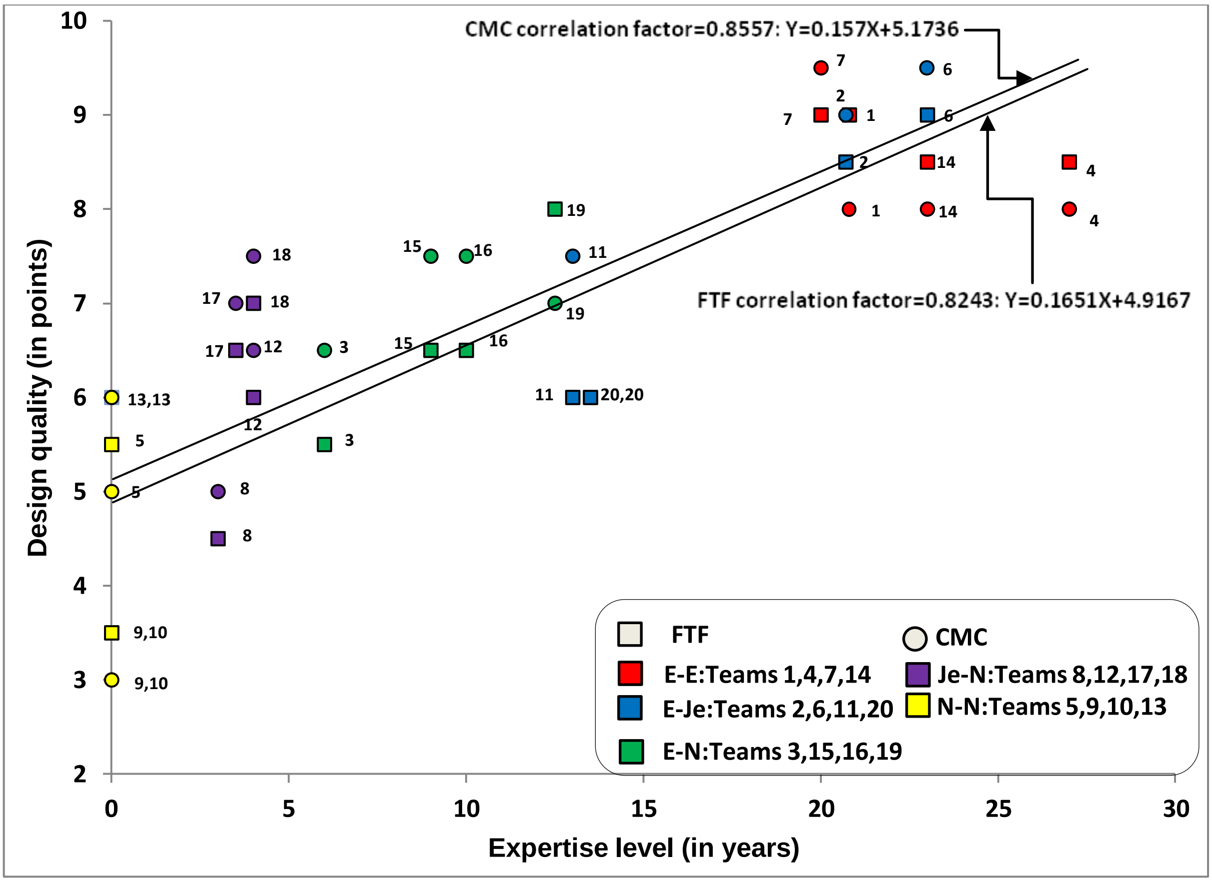


Figure 7.1: Level of expertise and team design quality in FTF and CMC

Generally, there is strong positive correlation between the level of expertise in years and design quality scores in the points for FTF and CMC, as indicated by the correlation factors of 0.8243 and 0.8557 respectively. The slopes of the two best-fit straight lines for FTF and CMC are nearly the same, which indicates that the effect of expertise level is the same for both methods of communication.

7.3.2 Emotional Profile

The emotional profile for users is defined and discussed in Section 4.8. It has already been shown that there is a relationship between the emotional profile and team productivity (see Section 5.3.1) and degree of collaboration (see Section 6.4.2). This section studies the impact of the three categories of emotions (positive, negative and neutral) on design quality, in FTF and CMC.

7.3.2.1 Total Positive Emotions

Figure 7.2 shows the relationship between the total positive emotions for the team (i.e. the sum of scores of positive emotions for User1 and User2, see Section 5.3.1.1) with team design quality, for both FTF and CMC. The general trend of the figure illustrates that there is a strong positive correlation for CMC and moderate for FTF, as indicated by the correlation factors of 0.8441 and 0.7719 respectively. The slope of the fit-best straight line for CMC is slightly higher than FTF; this indicates that the relationship between total positive emotions with design quality for CMC is also slightly higher than FTF. There is also indication that the highest expertise groups are in the top right corner (i.e. high design quality and high positive emotions) while the lowest expertise groups are in the bottom left corner (i.e. low design quality and high positive emotions). There are thus two possible inferences from the results. It can be said that where the users behave positively when discussing a task, the design quality increases. However, it could also be true that, more fundamentally, *both* positive emotions *and* design quality (as verified in Figure 7.1) are functions of team expertise, and thus it is really the expertise level that is controlling the apparent correlation in Figure 7.2. It would seem therefore that there are a few inter-related parameters here, and it is not easy to establish causality, or say precisely how two specific parameters independently correlate with each other.

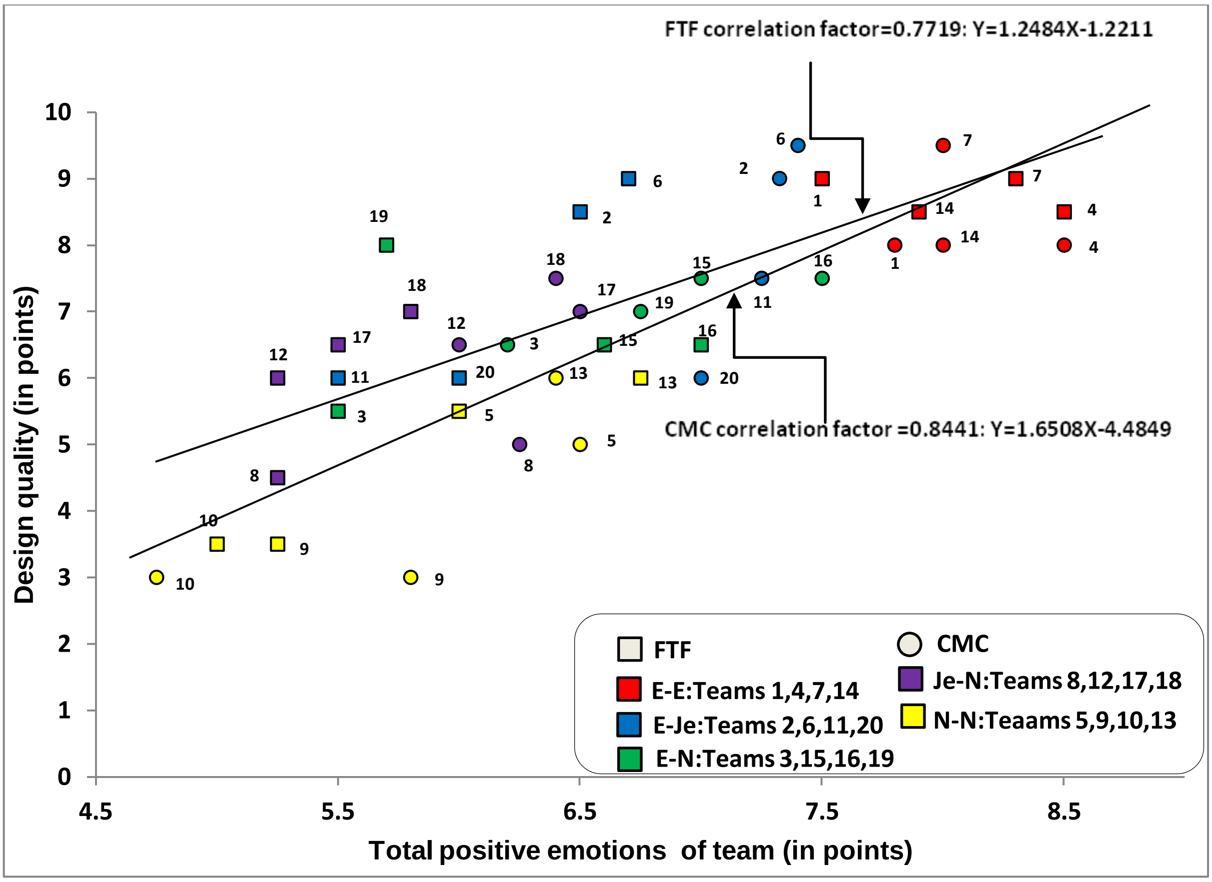


Figure 7.2: Total positive emotions and team design quality in FTF and CMC

It is clear that, the team type Expert-Expert has a good score in design quality as well as in the total positive emotions. Conversely, the teams from category Novice-Novice or Junior expert-Novice have low scores for both design quality and total positive emotions. Overall, the higher the positive team emotions, the better is the team design quality. This result is consistent with previous results which proved that the total positive emotions increase team productivity (Section 5.3.1.1) and the degree of collaboration (Section 6.4.2.1).

7.3.2.2 Total Negative Emotions

Figure 7.3 shows the relationship between the total negative emotions for each team and team design quality for FTF and CMC. As can be seen, there is a moderate negative correlation between the two, as indicated by the correlation factors of -0.7391 and -0.7606 respectively. The slopes of the two fit-best straight lines for FTF and CMC are nearly equal; this indicates the effect of the total negative emotions on the design quality is of the same degree for both FTF and CMC.

It can be seen in Fig. 7.3 that, the teams type Expert-Expert have good score in design quality and total negative emotions. There is a relatively wide spread of the negative emotion values for the Expert-Expert teams, but yet, the design quality is still nearly the same for these teams. However, in the other team types, variation in the negative emotions scores are also accompanied by variation in the design quality score. This indicates the Expert-Expert users are less affected by total negative emotions compared with users in other team types. The reason may be that the nature/complexity of the task is relatively low compared to the level of expertise in the Expert-Expert teams, and hence the quality of the resultant design is insensitive to the impact of negative emotions. There is also a similar picture obtained in Section 5.3.1.2 (Fig. 5.2) where the team productivity is also largely invariant despite the variations in negative emotions.

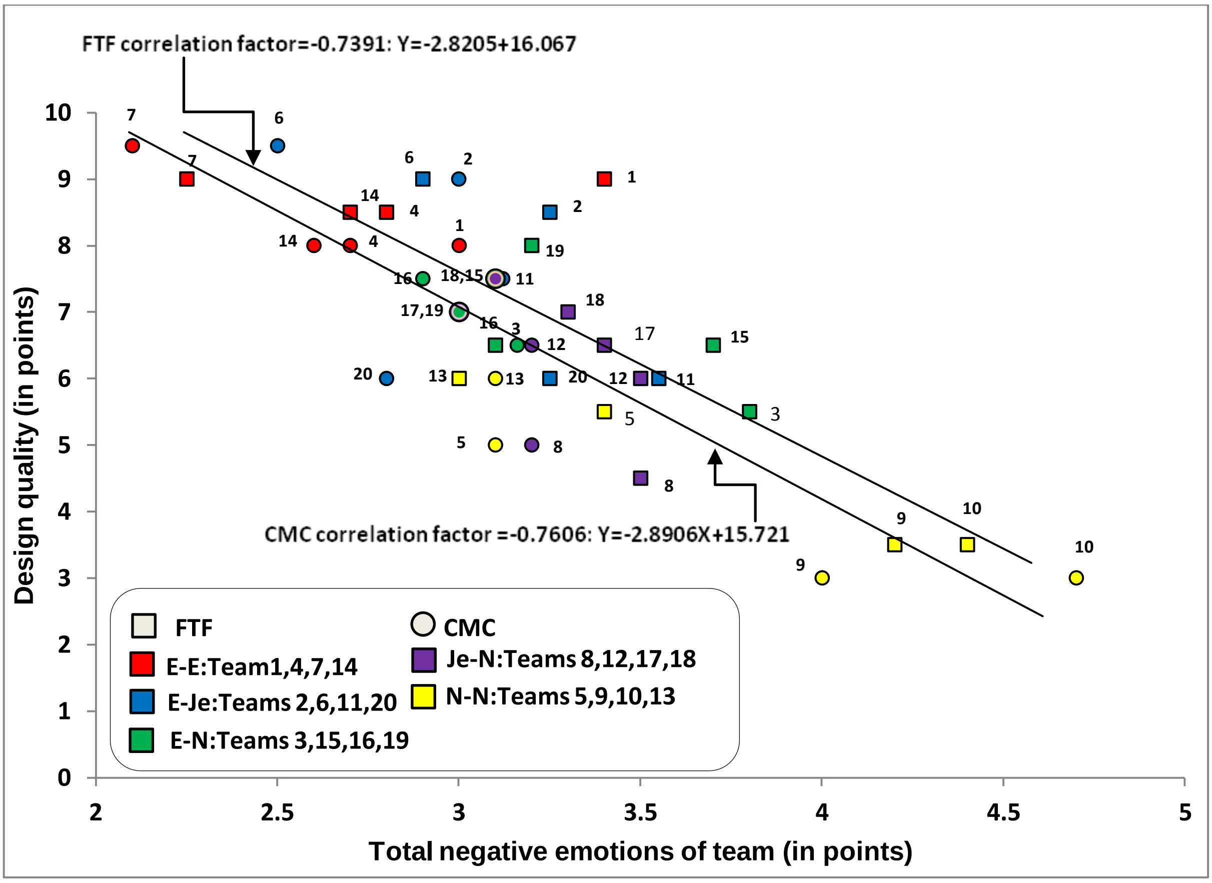


Figure 7.3: Total negative emotions and team design quality in FTF and CMC

Generally, as the total of negative emotions increases, the design quality and thereby the team performance decreases. These results are also consistent with the results in the previous sections which considered the relationship between the total negative emotions for the team and other team parameters, such as team productivity and the degree of collaboration (See Sections 3.5.1.2 and 6.4.2.2).

7.3.2.3 Total Neutral Emotions

For the neutral emotions, as can be seen in Fig. 7.4, there is weak correlation between the team design quality and the total neutral emotions for the team in FTF and CMC, as indicated in the correlation factors of 0.4068 and -0.4752 respectively. The slopes of the two best-fit straight lines are reversed, with positive slope in FTF and negative slope in CMC. As previously, the Expert-Expert teams have a large spread in neutral emotions; this is also observed for other team types but to a lesser extent. It is clear in Fig 7.4, most of the teams types are clustered around a score of 6 for neutral emotions, and this means most teams have the same level of neutral emotions. Overall, it can be inferred that there is no relationship between the design quality and the total neutral emotions. These results consistent with the previous results in Sections 5.3.1.3 and 6.4.2.3.

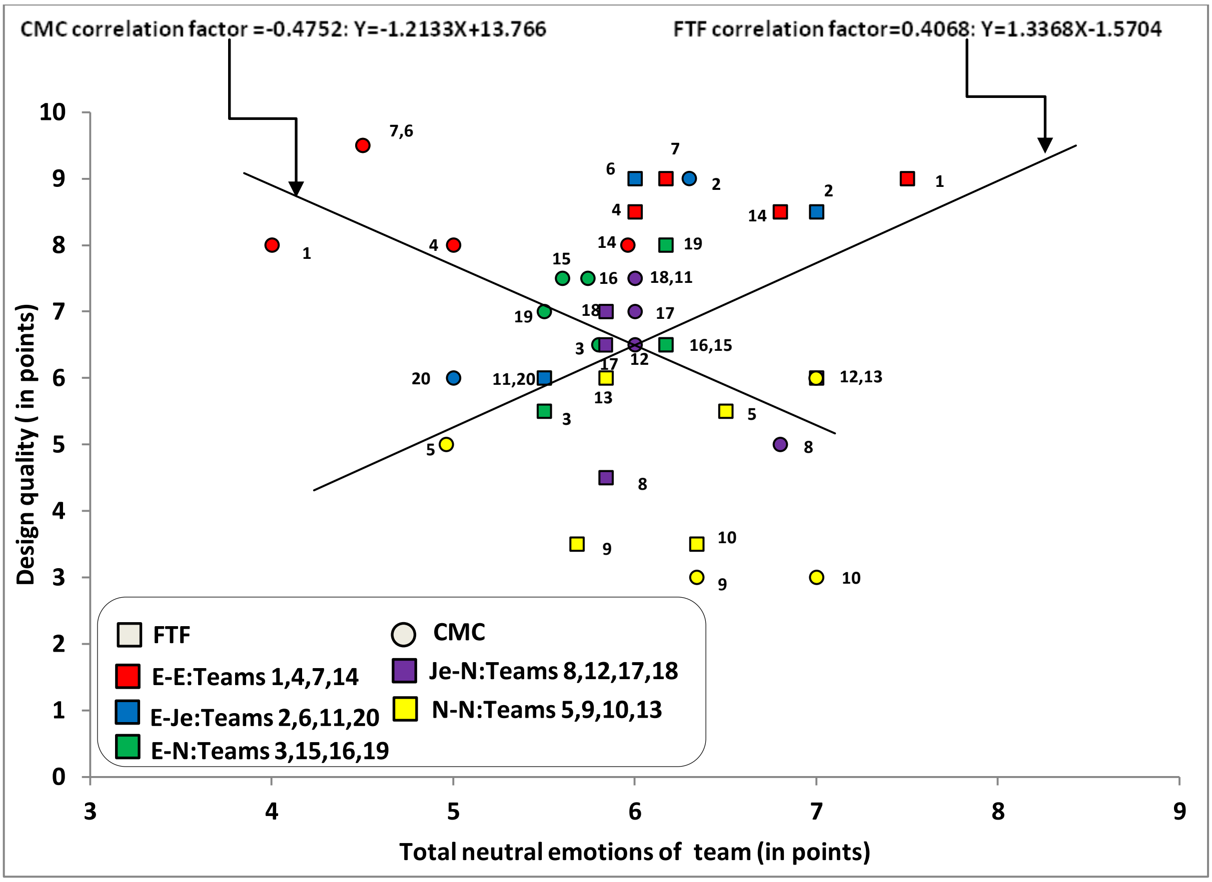


Figure 7.4: Total neutral emotions and team design quality in FTF and CMC

7.4 Design Quality Relationships

After studying the most important factors affecting team design quality for FTF and CMC, it is interesting to observe the relationship of design quality with the other outputs of the teams. This section illustrates the relationships between the design quality and other parameters such as team productivity and the degree of collaboration.

7.4.1 Design Quality and Team Productivity

Figure 7.5 illustrates the relationship between team productivity and design quality for FTF and CMC. As can be seen, there is a strong relationship for both FTF and CMC, as indicated in the correlation factors of 0.8780 and 0.8223 respectively. The slopes of the two best-fit straight lines are nearly equal; it is evident that, design quality is affected to the same degree by team productivity for both methods of communication. Therefore, this research suggests that when the team productivity increases the design quality score increases. For all the teams, the design quality and team productivity appear to depend largely on the team type and this is essentially reliant upon the teams' expertise. Hence, the teams which have a good score in design quality have users with good design expertise.

In addition, it is obvious that there is a difference between the design quality of the same team type. For example, the Expert-Expert teams have more or less the same team productivity but they do differ in design quality; this is may be due to the individual efficiency of some of the teams and users.

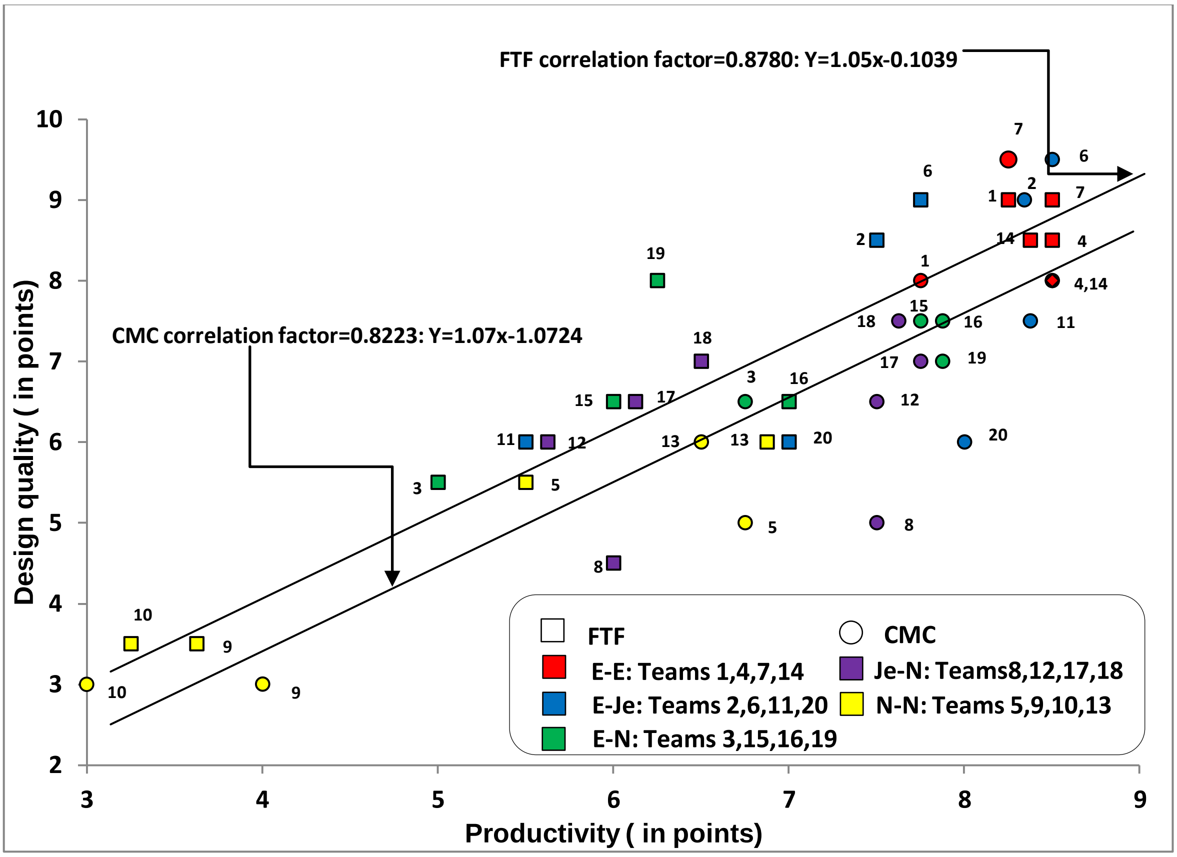


Figure 7.5: Team productivity and team design quality in FTF and CMC

7.4.2 Design Quality and the Degree of Collaboration

Figure 7.6 shows the relationship between design quality and the number of exchanges, the latter being the main indicator for the degree of collaboration. As can be seen, a moderate relationship does exist in FTF (correlation factor of 0.6883) and CMC (correlation factor of 0.7568). The slope of the fit-best straight line for CMC is slightly higher than for FTF, which also indicates that design quality in CMC is slightly more affected by the number of exchanges than in FTF.

It can be seen that team type Expert-Expert as well as team type Expert-Junior expert have good scores in both categories, while teams type Novice-Novice have the lowest score, with the other teams being located between them, However, there are large overlaps between all the team types. It is clear from Fig.7.6 that the spread across the Expert-Expert teams for number of exchange is large but the design quality is still the same. This indicates that design quality is not much affected by degree of collaboration for Expert-experts as compared to other team types.

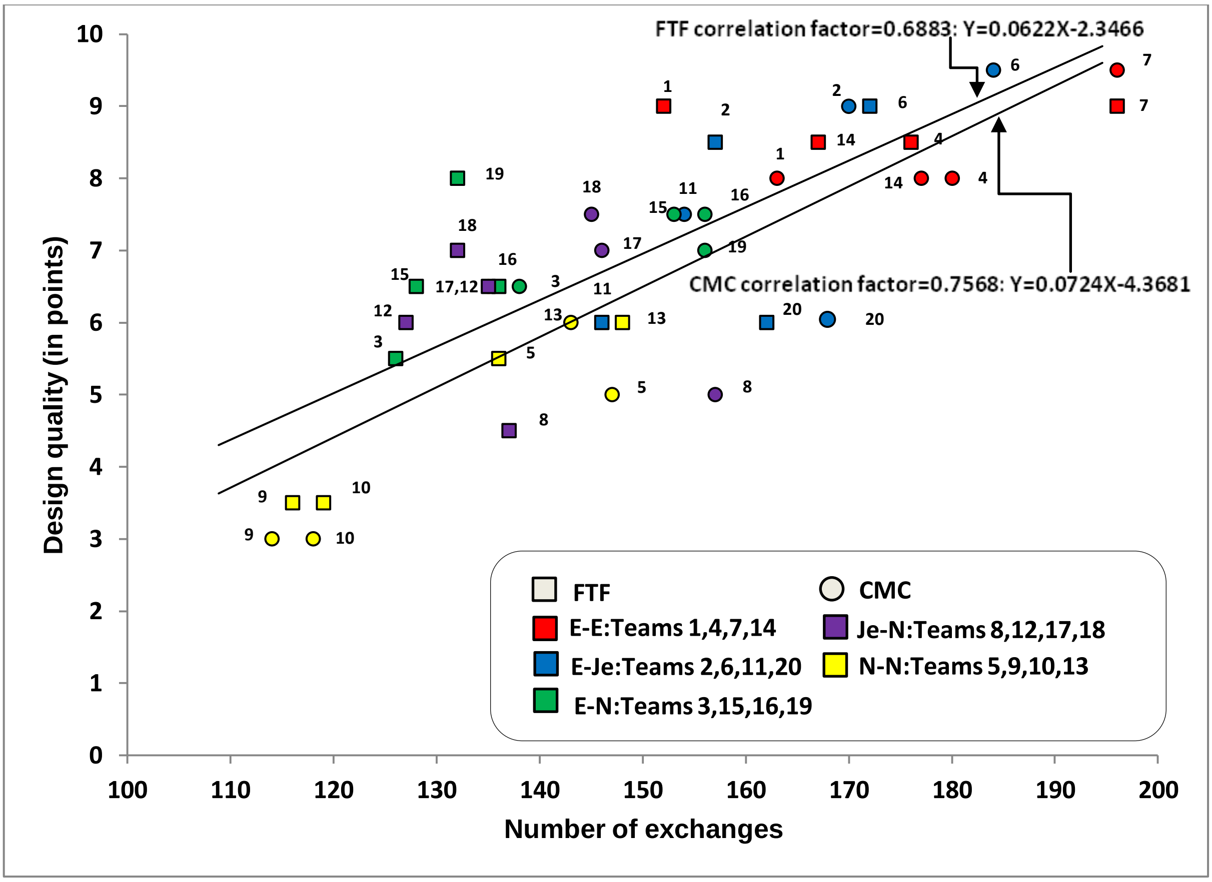


Figure 7.6: Number of exchanges and team design quality in FTF and CMC

7.5 Comparison between Individuals and the Team in Design Quality

This section explains the difference between the design quality of the team, and the design quality of a single user working alone undertaking the same design task. In order to do this, nine experiments were conducted, by three users in each of the three expertise levels, Expert, Junior expert and Novice, the task used by single user was FTF task (see Section 5.5). The requirements and conditions in these single-user experiments are the same as in the team experiments, i.e. a person using Revit on a computer working to a set of instructions and design brief similar to that in used for the teams. The time for each experiment was still 35 minutes to achieve the task. An average of the score for design quality has been taken for each category of user, as shown in Table 7.3.

Table 7.3: Average of individual design quality for the users according to their level of expertise

User's type	Averages design quality in (points)
Expert	7.50
Junior expert	5.00
Novice	4.00

Figure 7.7 illustrates the relationship between the average design quality for the teams and single user with the team type or user category. The horizontal axis consists of two axes for expertise level: the lower axis for teams and the upper axis for single users, scaled such that the expertise level of a team is comparable to the expertise level of a single user (see Section 5.5 where this was first introduced).

Figure 7.7 shows that the design quality for all the teams (both FTF and CMC) is higher than the design quality for the equivalent single user. These results indicate that the users obtain better design quality scores when they work as a team, and have a good environment to make good decisions through exchanging ideas. While it could be expected that productivity of a team would be higher than for an individual, it is not necessarily expected the resultant design quality would also be better for a team, especially given the additional overhead necessary for collaboration in a team. It would seem that, although the individual working alone has as much time and resources for the work, and has no need for consultation and discussion to take decisions, yet the collaborative environment is one where better ideas and decisions occur.

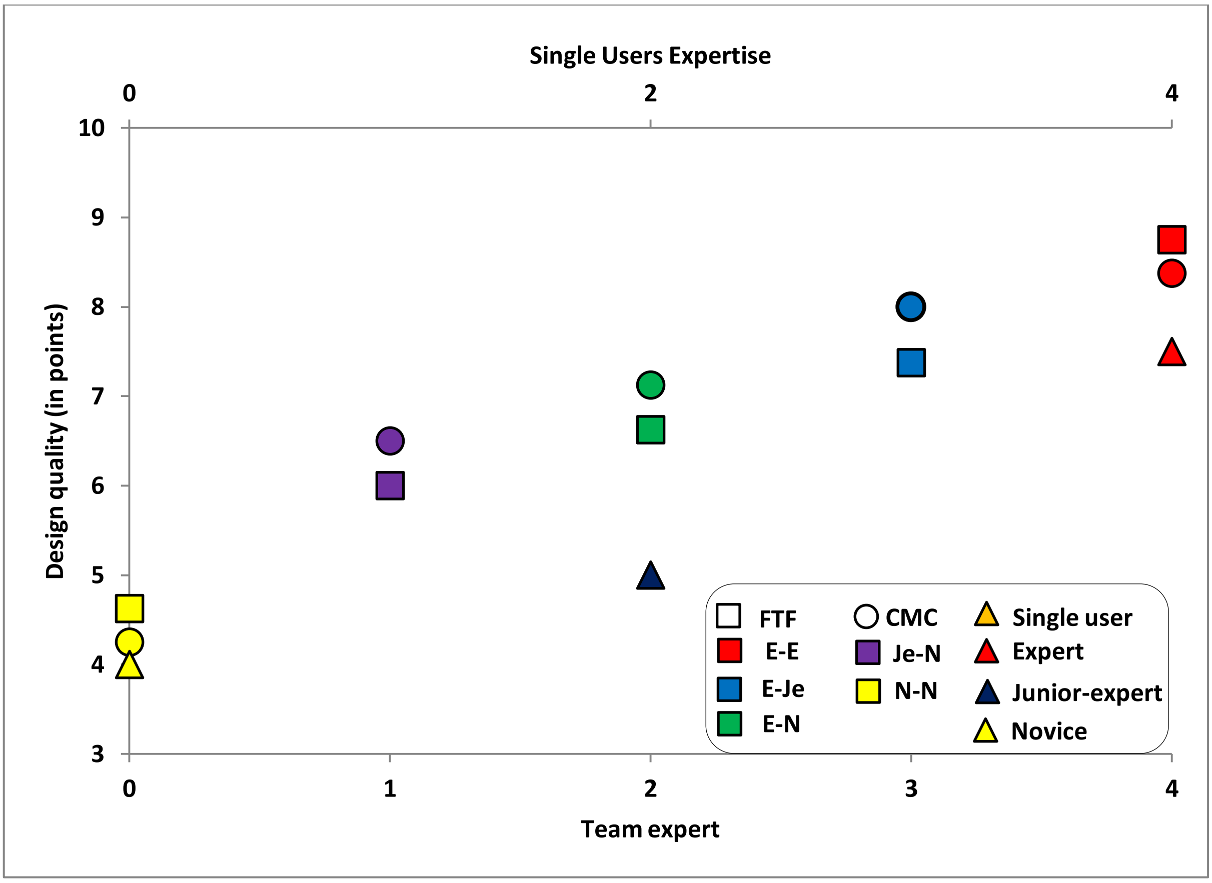


Figure 7.7: Average design quality for the team and the single user expertise

7.6 Summary

This chapter discusses the team design quality for FTF and CMC. The results show that there is a small difference in terms of the design quality between FTF and CMC. Listed below are the most important conclusions from this chapter.

1. The team design quality is nearly the same for FTF and CMC, with CMC producing the slightly higher design quality.
2. The average of design quality for team types Expert-Expert and Novice-Novice in FTF is slightly higher than for CMC, while the reverse is true for team types Expert-Junior expert, Expert-Novice and Junior expert-Novice.

3. There is a positive relationship between the teams' level of expertise and the design quality in FTF and CMC, and the effect of the expertise level on design quality is the same in both communication methods.
4. The design quality was affected positively by positive emotions and negatively by negative emotions, and there is no relationship between the design quality and neutral emotions.
5. There is a positive relationship between the design quality and team productivity, and also with degree of collaboration.
6. The design quality for the teams in the two methods (i.e. FTF and CMC) is higher than the single user design quality.

Chapter 8

Non-verbal Communication in FTF

8.1 Introduction

This chapter studies some of non-verbal communication components for 20 teams for FTF and classifies them for the main five categories such as Emblems, Illustrator, Regulator, Adaptors and Affect display. This chapter divided into six main sections as follows:-

1- Section 8.2 explains the results analysis which is based on the expertise level where the teams are divided according to expert level of the users.
2- Section 8.3 studies the effect of group experience and explains the main five categories for non-verbal communication movements.
3- Section 8.4 considers the illustrator movements, temporal distribution of illustrators and what is the relationship between these types of movements and team productivity.
4- Section 8.5 explains the adaptor movements, temporal distribution of adaptor movements and the relationship between theses type of movements and team productivity.
5- Section 8.6 studies the regulator movements and the relationship between this type of movements and team productivity.
6- Section 8.7 explains the affect display movements and shows the meaning of these movements.

8.2 Analysis Method

The analysis of the results revealed that there are two distinct types of behaviour according to the experience levels of the users and therefore the results are presented in two categories as described below.

- Category A consists of 8 teams, the users in these teams all have similar level of expertise (i.e. similar pairing), e.g., Expert-Expert or Novice-Novice.

- Category B which represents the remaining set of 12 teams. The users in these have different experience level (i.e. dis-similar pairings) e.g. Expert-Novice, Expert-Junior expert or Novice-Junior expert.

8.3 Effect of Group Experiences

According to Hatem et al., (2012) whether the team members had similar levels of experience or not has an impact of how they behave. This particular aspect is now examined with respect to NVC, where the teams have been divided into two categories. The results in Fig. 8.1 show the occurrence of the five types of NVC movements for both teams with similar, and dis-similar, experience levels. The results are plotted separately for the two users. Figure 8.1 shows that the users exhibited principally “illustrator” movements alongside their speech, although “adaptor” movements were also noticeable. What is also very apparent that while there is little to distinguish between the two users when the pairings have similar level of expertise, there is a very significant difference when the pairing has dis-similar (i.e. uneven) experience. In the latter category, User1, the self-designated user who naturally mostly controlled the computer mouse and interfaced with the Revit model, is clearly the more “animated” in the collaboration between dis-similar pairs, with high number of both illustrator and adaptor movements, and at the same time, User2 is correspondingly more inert. The level of activity for these two users is respectively some 25% above, and 40% below, the near-identical average of the pairings with similar experience. Since the dis-similar pairings include both users with all levels of expertise, it is clear that the behaviour observed is not related to the experience level as such, but to the more controlling and domineering personality/behaviour of one of the users, and in all but two cases, the more domineering user was the one with the more experience, even when about half of these pairings were of complete strangers.

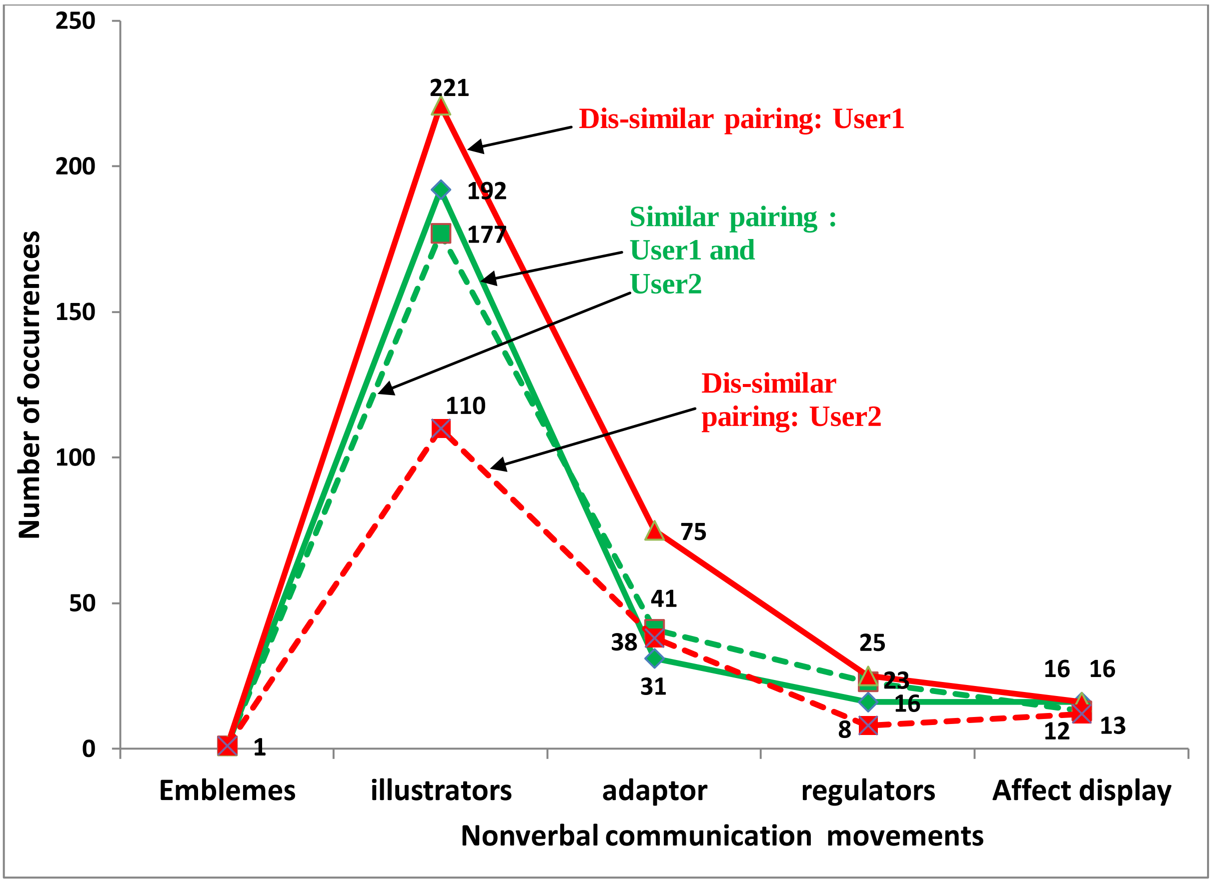


Figure 8.1: Average NVC movements in pairings with similar (Category A) and dis-similar (Category B) level of experience

Figure 8.1 shows that the curves for User1 and User2 for the dis-similar grouping form upper-and lower-bounds for the curves of the similar grouping. The users were all volunteers and the only aspect of planning in the pairing was in trying to achieve an even number of the different teams (i.e. a range of expertise). Who was paired with whom was dependent also on availability at the time. It is therefore interesting that the behaviour of a certain user is dependent on the nature (i.e. experience level) of the other team member, because in the dis-similar pairings, 84% of the users with the higher experience made themselves User1 and thus their behaviour is represented by the upper-bound curve in Fig. 8.1, while the same expert could have been teamed up with another expert, and they would probably on average have exhibited a lower number of NVC movements. The behaviour, in terms of NVC, of a person is thus as much affected by the experience level of the other team member, as by their own.

It is also useful to compare these results with those for verbal communication of the same users in the dis-similar pairing, where User 1 was responsible for 66% of total words spoken. This is also reflected in the results for productivity, with User1 being responsible for 67% of the total team productivity. It would seem that the greater use of NVC was linked to the fact that User1 spoke more and did more.

It contrast, where the pairings have similar levels of expertise (whether it be Expert-Expert or Novice-Novice), the two users have very similar usage of NVC, with User 1 being responsible for 52% of the number of words, and 53% of the team productivity. The overall picture therefore for the category A teams, is that the behaviour and performance of the users is very similar and one can infer that this is due to them having similar levels of expertise.

8.4 Illustrator Movements

A finer breakdown of the different illustrator movements is shown in Fig. 8.2. For Category A where both users have similar experience level, User1 (averaging 192 movements) is slightly more active than User2 (averaging 177 movements) in most types of illustrator movements, but the different is small. About half of the movements come from intensive staring at an object, which emphasises some aspects of the object for greater attention.

Where the two users have dis-similar experience levels, User1 was much more active than User2 both overall (by a factor of two) and across every type of illustrator movement. Actually, the corresponding ratio for number of words spoken is also nearly twice (1.9), so clearly User1 made much more use of NVC to emphasise his/her spoken words. The data here also suggest that the illustrator movements are directly proportional to the number of words spoken. Figure 8.2 also shows that the difference between User1 and User2 is most pronounced in the first type of action, where it is seen that User1 assumes more overall control of the teamwork by speaking more, and controlling what points/objects are discussed.

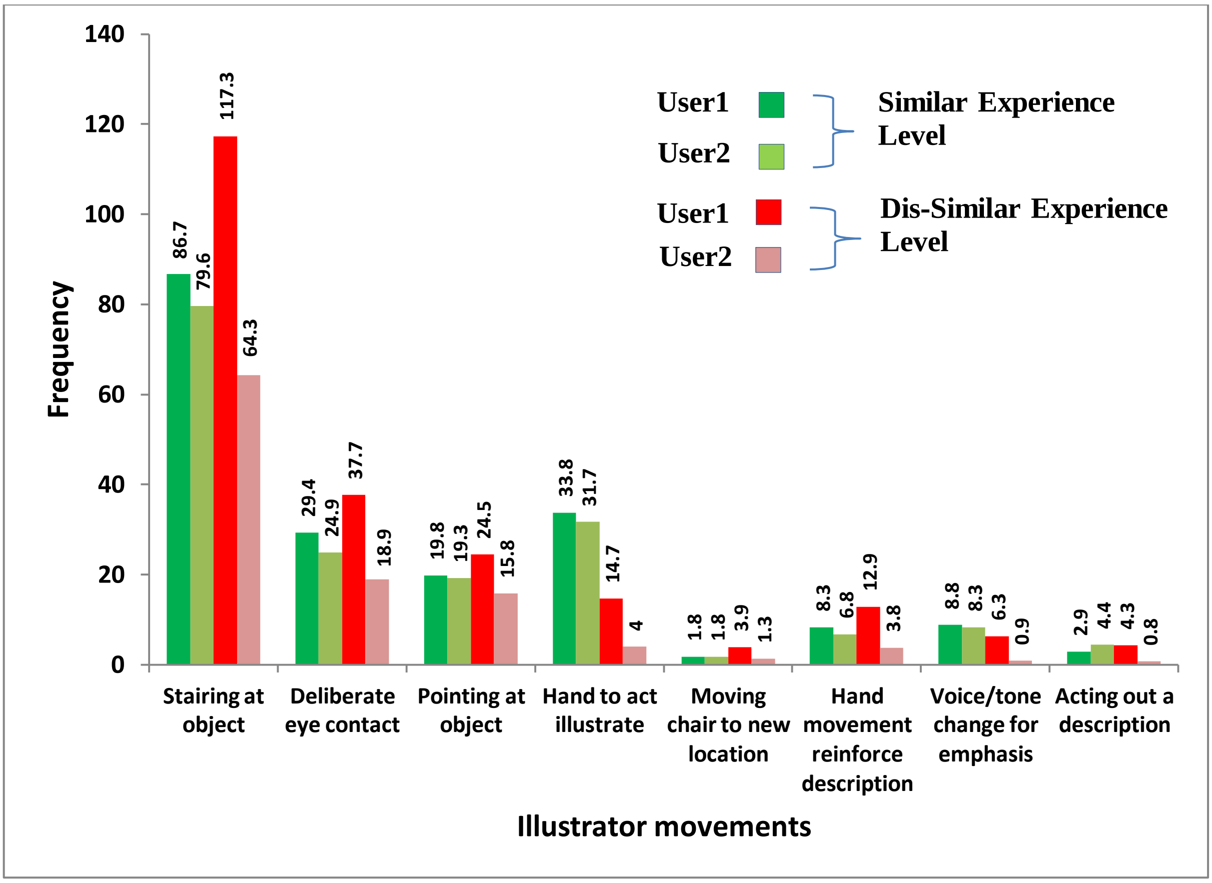


Figure 8.2: Distribution of type of "Illustrator" movements for different users

8.4.1 Temporal Distribution of Illustrators

Figure 8.3 shows the averages for illustrator movements for User1 and User2 as distributed over the time of the experiment. Where both users in a team have similar levels of experience, User1 is overall marginally more active than User2; this being most apparent in the middle part of the experiment, but both users are more equal in illustrator activity in the last 15 minutes.

Conversely, for teams where members have dis-similar levels of experience, after a fairly similar first five minutes, there is substantial difference between User1 and User2, with User1 having an average twice that of User2. As stated above, for all these 10 of the 12 teams, User1 turned out to be the team member with the greater experience level. Since illustrator movements are used to improve clarification of what is being described, then the more experienced team member had clearly taken on the role of being the guide, instructor and leader, the User1 for these teams was also found to be domineering (see Section 4.8). Where the two members of a team were of similar experience level, there is less need for one to explain to the other, and correspondingly, the number of illustrator movements is very similar for both team members.

For all teams, to a varying degree, there is an initially low number of illustrators, which is then followed by a rapid increase in the second interval, leading to a peak of movements around the half-way point before a significant decrease in movement in the last 15 minutes. This pattern is consistent with the observation that initially, after social greetings, the team spend time reading and studying the brief, and hence the first few minutes are somewhat quiet. The teams thereafter enter a stage of highly active working, in which the number of illustrator movements (and number of words) are at a high level, and this lasts, for 15-20 minutes. After this, it is observed that most teams seem to begin to get distracted, or to enter a lull with an appearance of self-satisfaction with progress, or to disagree about the work. For the remainder of the time, most teams then increase their activity just before the end of the time limit. These four observed phases are each reflected in the number of illustrator movements (and number of words).

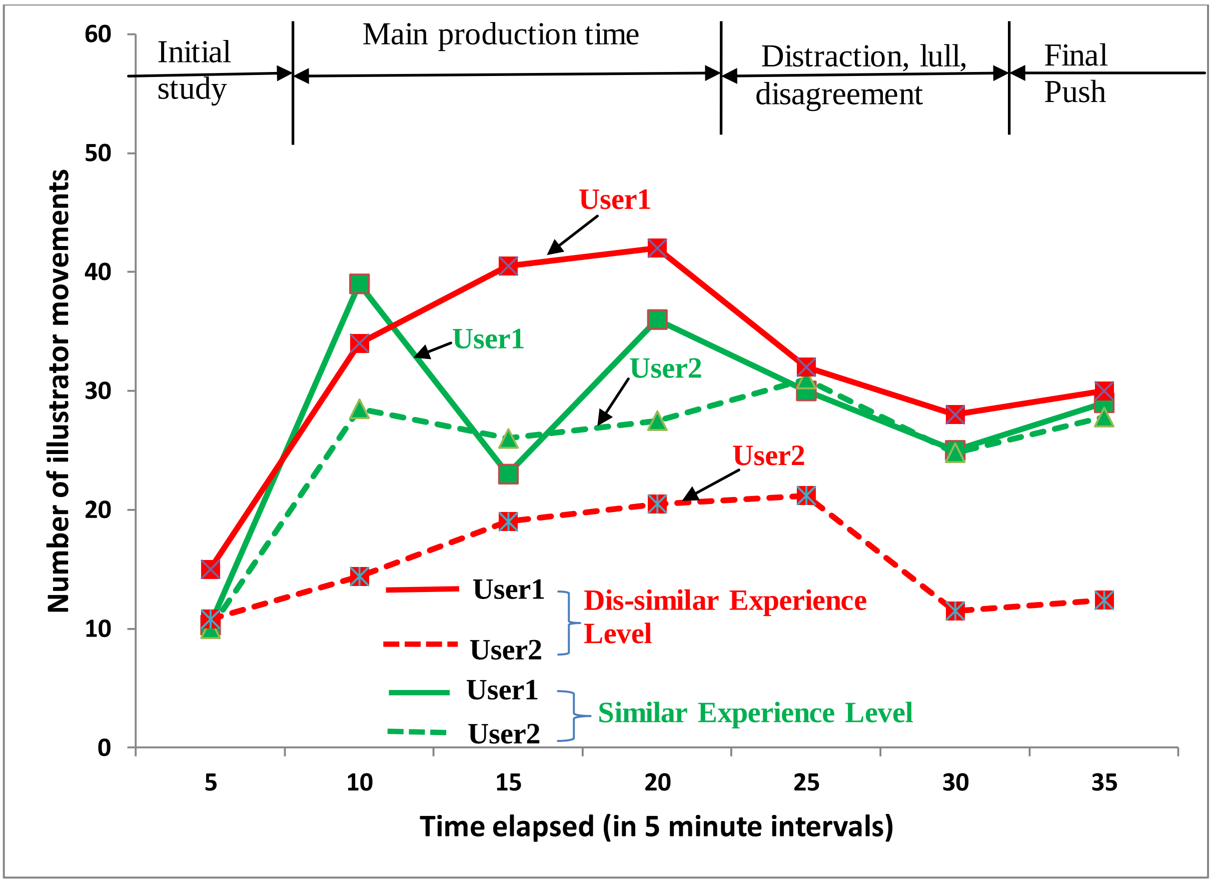


Figure 8.3: Relationship between the numbers of illustrator movements over the length of the experiment

8.4.2 Team Productivity and Illustrator Movements

Apart from evaluation of the processes in the design collaboration, it is also important to evaluate the product of the collaboration. In this design, productivity is accumulated though completing the different tasks to improve/correct the model. It is therefore useful to compare the progress of productivity in the experiments, with the accompanied processes over the duration of the experiments. Figure 8.4 shows the number of illustrator movements (in each 5-minute interval) superimposed on the productivity achieved in those intervals.

It is clear from Fig. 8.4 that there is a close correspondence between shape of the bar chart for productivity and the curves for illustrator movements. Both of these start low, and increase to a high level over the "main production" stage, decreasing in the "distraction" stage, before increasing again in the "final push" stage. Spearman's rank correlation has been calculated to show correlation values of 0.72 and 0.82 for the similar and dis-similar groupings respectively, which shows a reasonable correlation between illustrator movements and productivity. It can be argued therefore that illustrator movements in FTF collaborative design are desirable in that they accompany, and even promote, productivity.

It should be noted that while the four stages in the experiments have been identified in Section 8.4.1 arising from the level of activity, they are now seen to equally apply to the level of productivity. There is therefore a correspondence between the rate of illustrator movements and the rate of productivity.

It is also notable that the group with similar experience level have a slightly higher number of illustrator movements (369, compared to 331) and a higher productivity (6.8, compared to 6.3), but the difference is small. In an earlier chapter it was found that productivity was largely influenced by the level of experience (see Section 5.3.2). In this analysis, the two groupings have a range of experience but the average experience for the two groups is similar, and hence there is little impact seen in Fig.8.4.

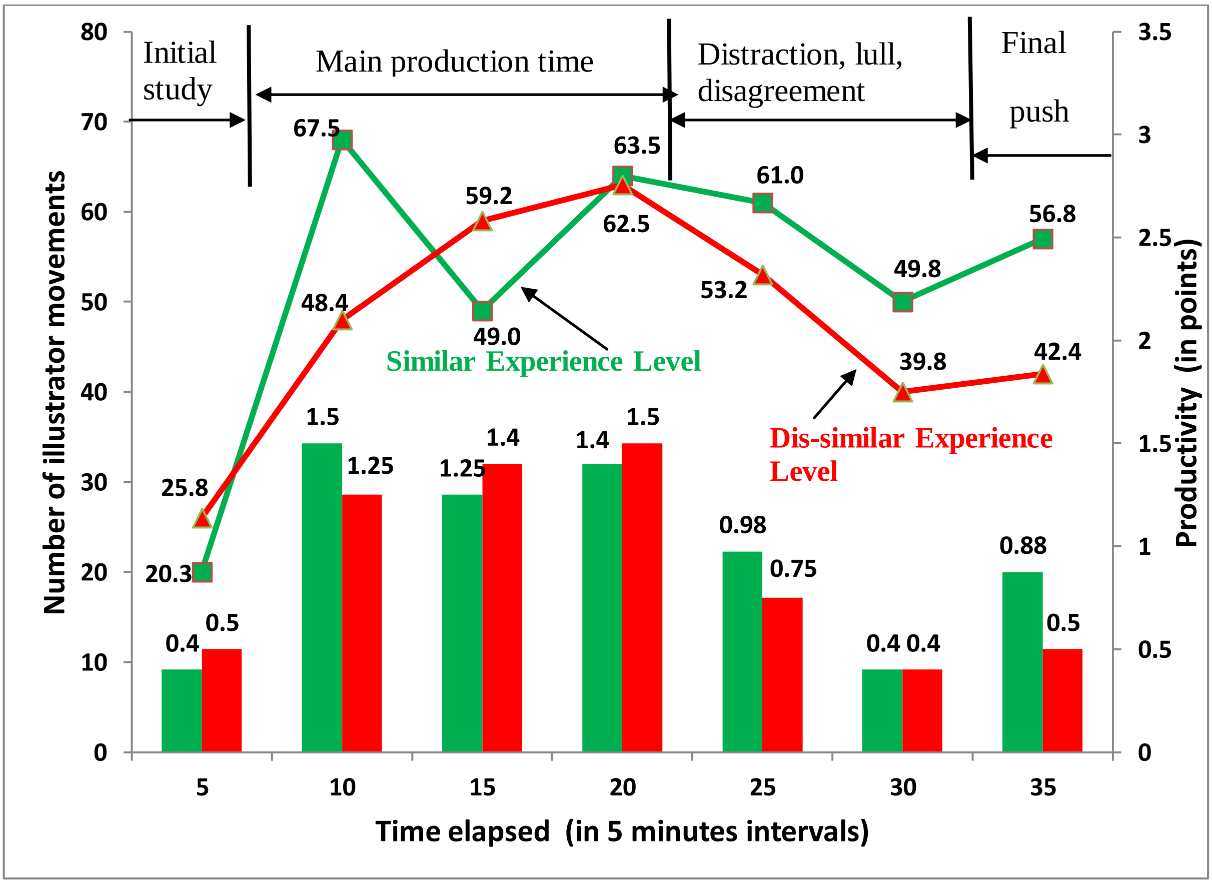


Figure 8.4: Temporal distribution of productivity illustrator movements

8.5 Adaptor Movements

Figure 8.5 shows the average distribution of the different adaptor movement recorded in the experiments. For teams made up of users with similar experience level, it is User2 (41) who made slightly greater use of adaptors than User1 (31). The main actions are those relating to “hand on cheek/chin/forehead” (i.e. thinking), “changing position in chair” (i.e. principally re-positioning for work, but sometimes for personal comfort) and “vertical head nod (i.e. agreement). Interestingly, there is almost no use of the “head shake”, which is a fairly abrupt signal of disagreement, in this group. All of these points to the pairings working well together and being of similar strength personalities. Generally User2 exhibits signs of being slightly more active in terms of thinking, evaluating and decision making.

On the other hand, for User1 displays much greater number of adaptor actions (75) than User2 (38) in the pairings with dis-similar experience level. This is most pronounced in the action of “changing position in chair” (29.5 vs. 6.8), which, in these experiments, is principally due to re-positioning of the body, e.g. as a user moves from the computer to face the other user, etc. While it can be expected that User1 might re-position more frequently, since they are the controller of the computer mouse (and hence the computer), it is also notable that the User1 in the other grouping (i.e. teams of similar experience level) in fact showed fewer such actions than User2. The much larger number of body re-positionings for User1, in teams with dis-similar experience, is in fact due the User1 (who is typically the more experienced of the pair) not only doing, but also explaining, the work, i.e. dominating the work. This is consistent with the much higher occurrence of User2 passively agreeing by the use of head-nods, User2 also shows embarrassment by covering of the mouth while speaking (by ratio of over 25), User1 has nearly 21 times more head-shakes (i.e. a coarse rejection gesture) than the other user, and User1 has more thinking actions (28 vs. 13).

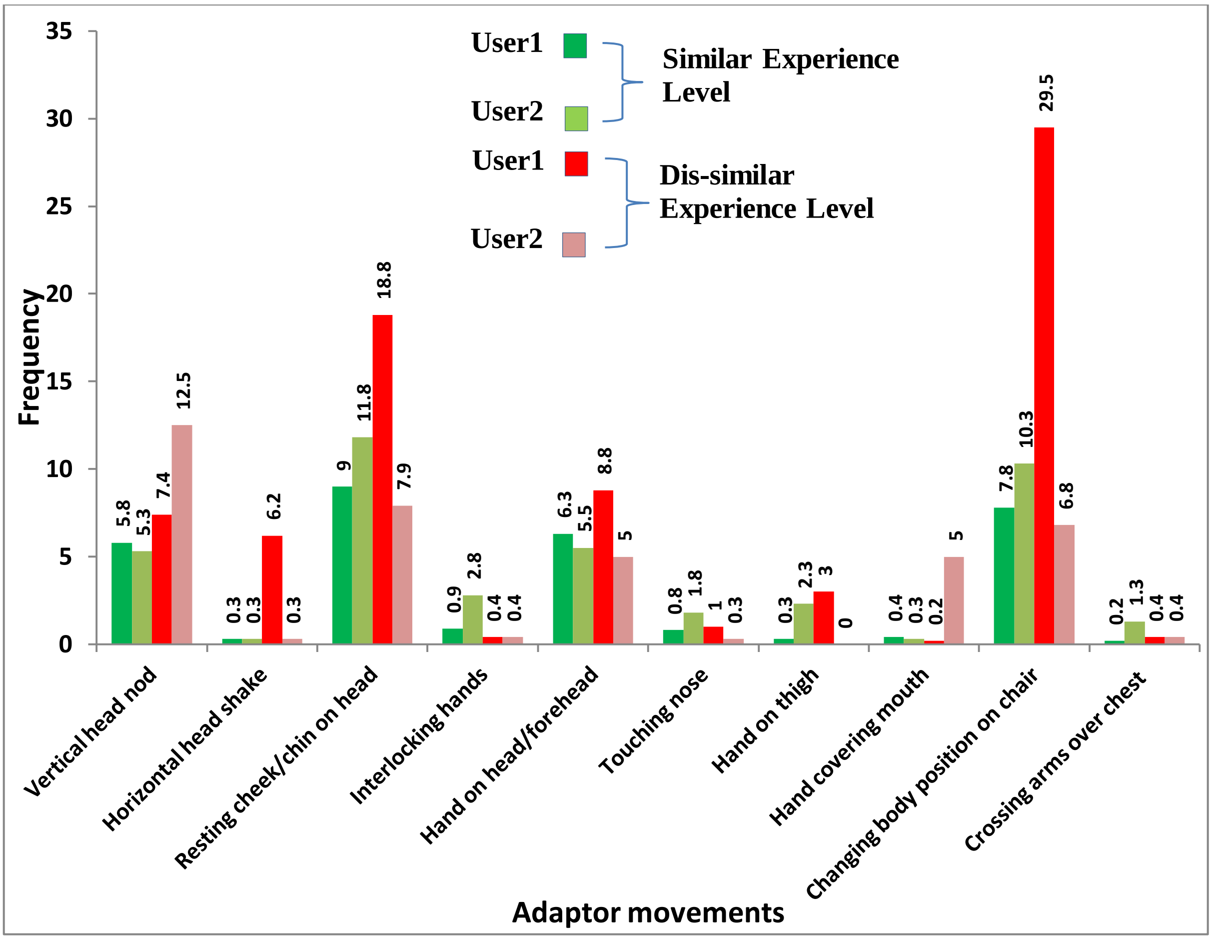


Figure 8.5: Distribution of type of "Adaptor" movements for different users

8.5.1 Temporal Distribution of Adaptors

The observations concerning User1 are further reinforced in Fig. 8.6 which shows the distribution of adaptor movements over time. User1 of the teams with dis-similar experience level again stands out prominently by displaying many more adaptor movements, while the other three curves overlap each other to the point that they are not particularly distinguishable. Furthermore, while User1 typically has a higher number of adaptors, most of these occur in the main-production stage. User1's adaptor movements are thus related to work, even though the dominating characteristics might arguably also be having a negative impact on the work.

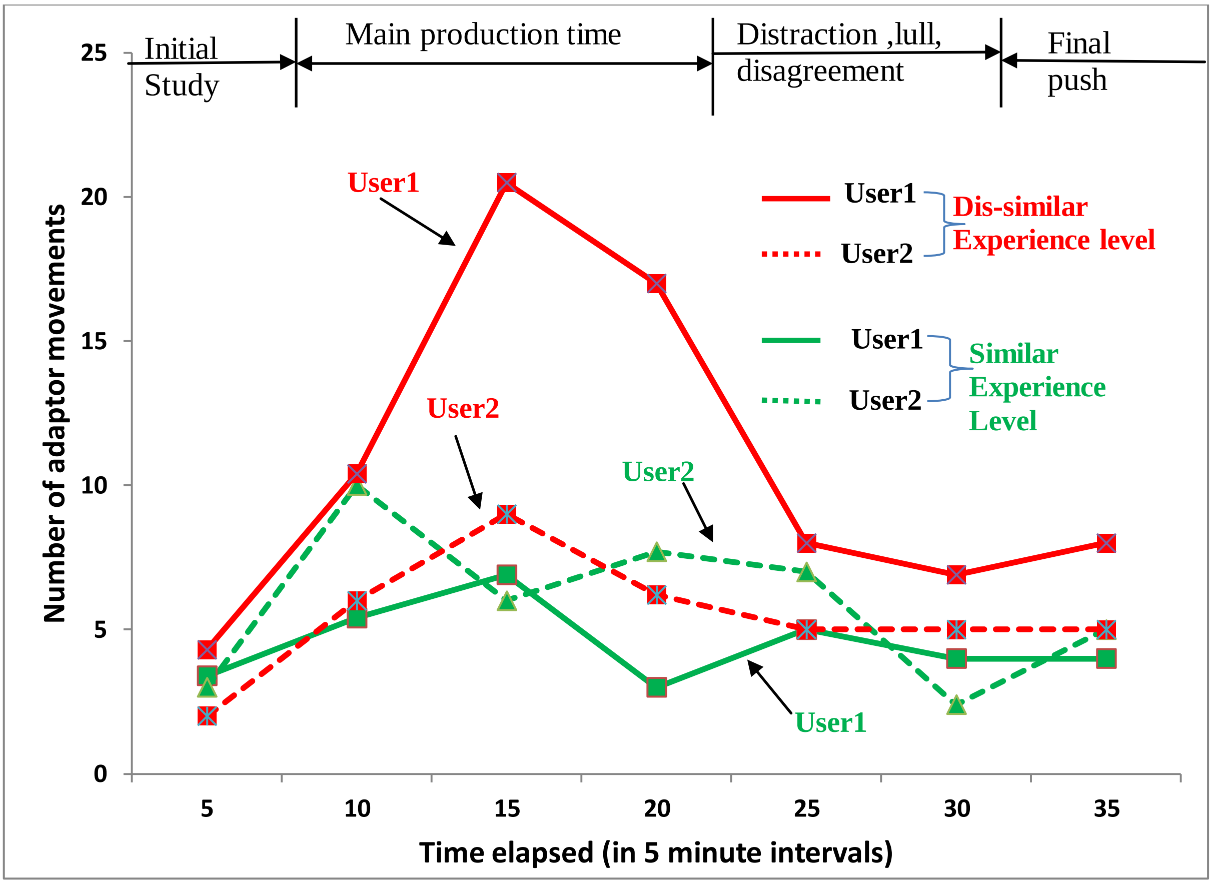


Figure 8.6: Relationship between the number of adaptor movements over the length of the experiment

8.5.2 Team Productivity and Adaptor Movements

The impact of these movements can be deduced by observing the productivity over time (see Fig. 8.7). Generally, it can be seen that there is good direct correspondence between the number of adaptor movements and the level of productivity, with Spearman's rank coefficients of 0.89 and 0.85 for teams with similar, and dis-similar, level of experience respectively. In this respect, the adaptor movements are similar to the illustrator movements in that they both accompany and positively affect productivity. This is perhaps more noticeable from observing the data due to User1 of teams with dis-similar experience level, since this User1 singularly dominates the number of adaptor movements, and this happens most especially in the last two-thirds of the "main production" stage (i.e. time periods 15 and 20 minute), and it is in these two periods that the highest productivities are observed.

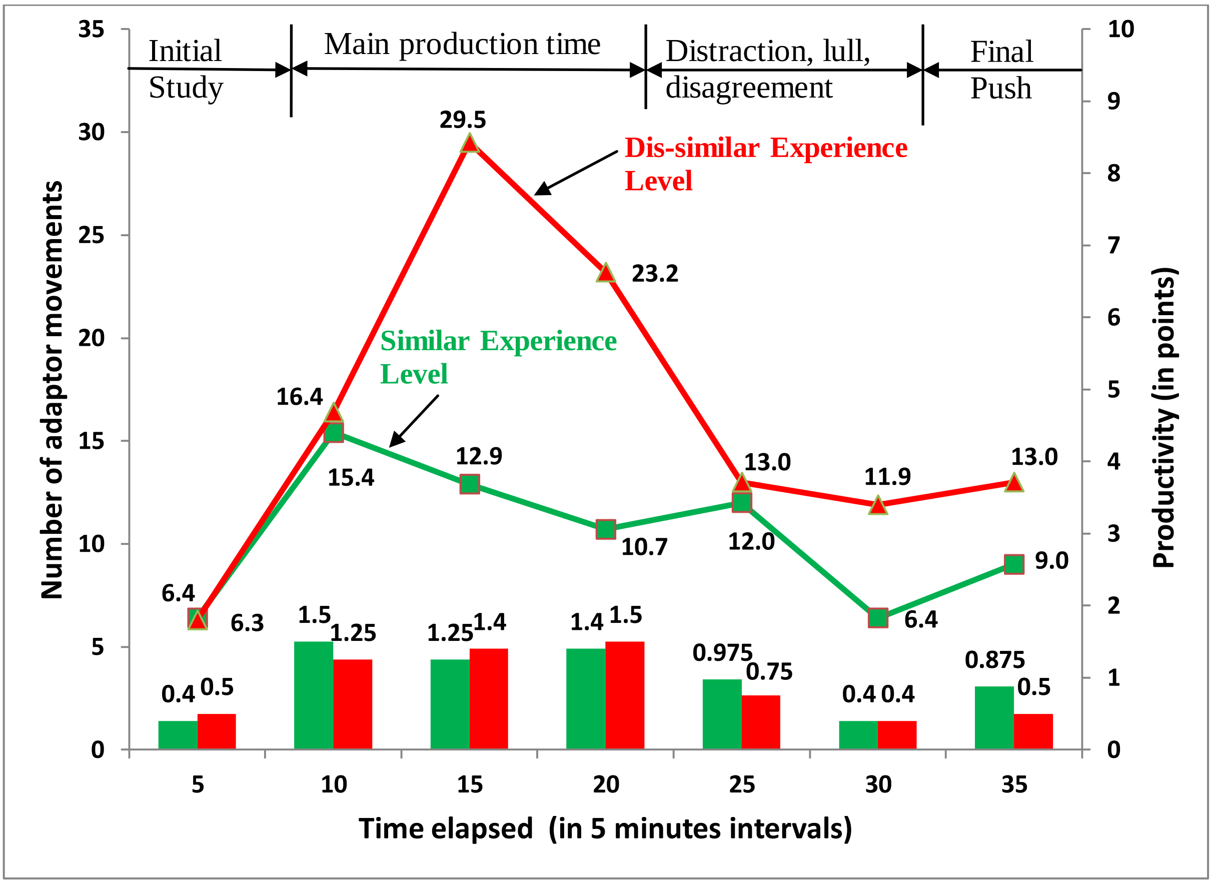


Figure 8.7: Temporal distribution of productivity adaptor movements

8.6 Regulator Movements

The illustrator movements of NVC accompany, support or enhance verbal communication, but they are generally not made in place of verbal communication. On the other hand, regulator movements can be made independently of any accompanying verbal communication. Figure 8.8 shows the number of regulator movements, for the various types of regulator actions observed in these experiments. For all users, the main regulator action is the use of a hand to interrupt the speech of the other speaker. This was used more by the group with similar experience (evenly between the two users) but in the group with dis-similar experience level, it was User1 who prominently interrupted with a hand action while User2 was speaking. This is consistent with the earlier observation of the more experienced member in an uneven team (User1) being domineering. Although the other regulatory actions were infrequent, it is notable that User1 in the dis-similar experience grouping was also prominent in the use of the hand to both reject User2's suggestions, and cut short User2's speech. Again, this is consistent with domineering behaviour.

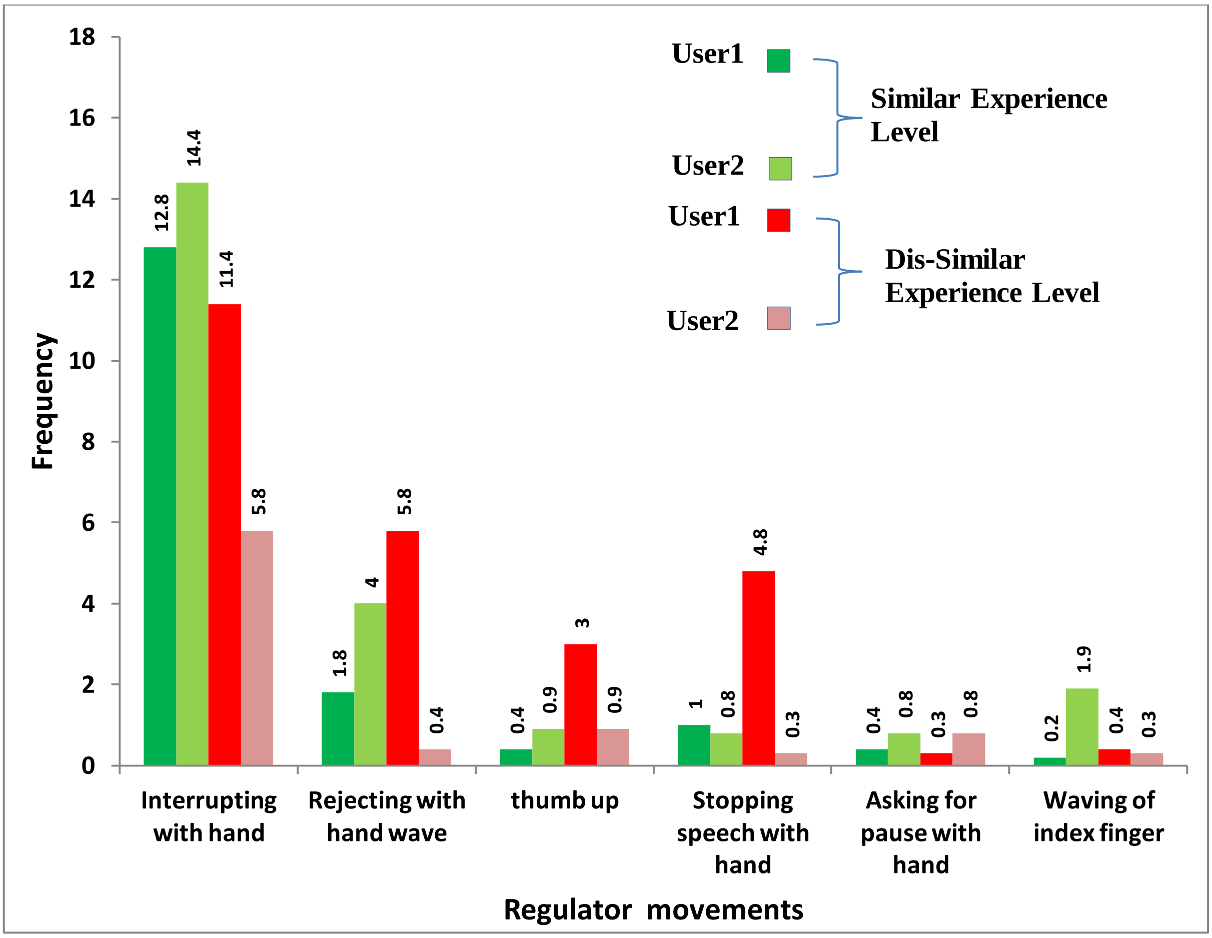


Figure 8.8: Distribution of type of "Regulator" movements for different users

Although the number of regulator movements is small, there is a significant message when that number is compared to the productivity, see Fig. 8.9. Unlike Figs. 8.4 and 8.7, the curves for these NVC movements tend to run counter to the bar chart for productivity. There is generally a reduction in regulator movements in the main "production stage" where productivity is high and a sharp increase in regulator movements in the "distraction stage" where productivity is low. Unlike the illustrator movements which enhance and support verbal communication, and are a positive influence on productivity, the regulator actions observed are almost entirely ones that disrupt verbal communication, reduce agreement, and delay decision taking, all of which in turn seem to reduce productivity.

Although both groups have a similar pattern of regulator movements across the four stages of an experiment, the teams with dis-similar experience level have a continually high level of regulator movements, compared to teams with similar experience level. This would suggest that teams with a similar level of experience (whether Expert-Expert or Novice-Novice) are more able to work more harmoniously.

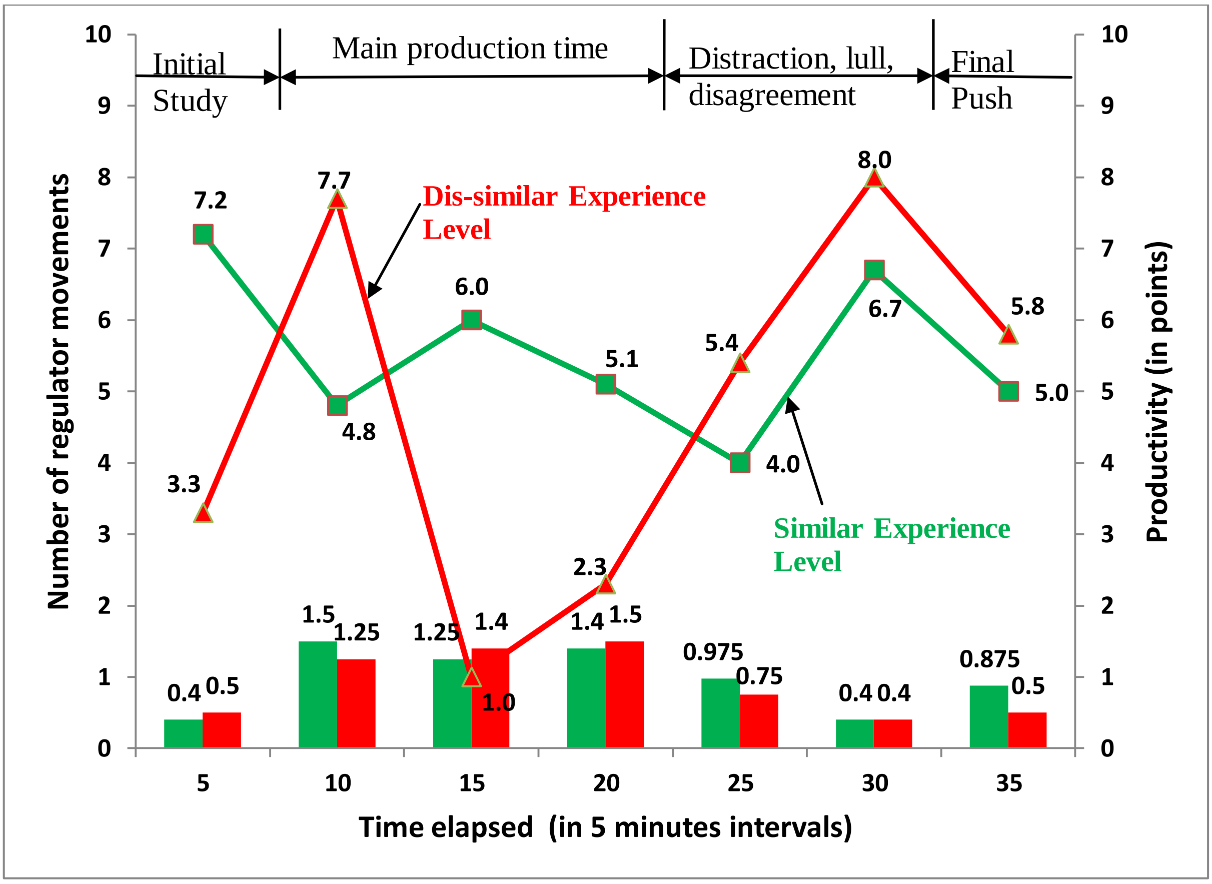


Figure 8.9: Temporal distribution of productivity regulator movements

8.7 Affect Display Movements

Generally for both categories User1 made more use of "Affect Display" than User2, as shown in Fig. 8.10. For the category similar experience level, User1 makes 16 of this type of movements in 35 minutes while User2 makes 13, so overall the usage of this type of communication is low.

For the category dis-similar experience level, User1 made slightly more use than User2 with User1 making 16 movements and User2 12 movements. The difference between the two indicates that User1 was more at ease and relaxed.

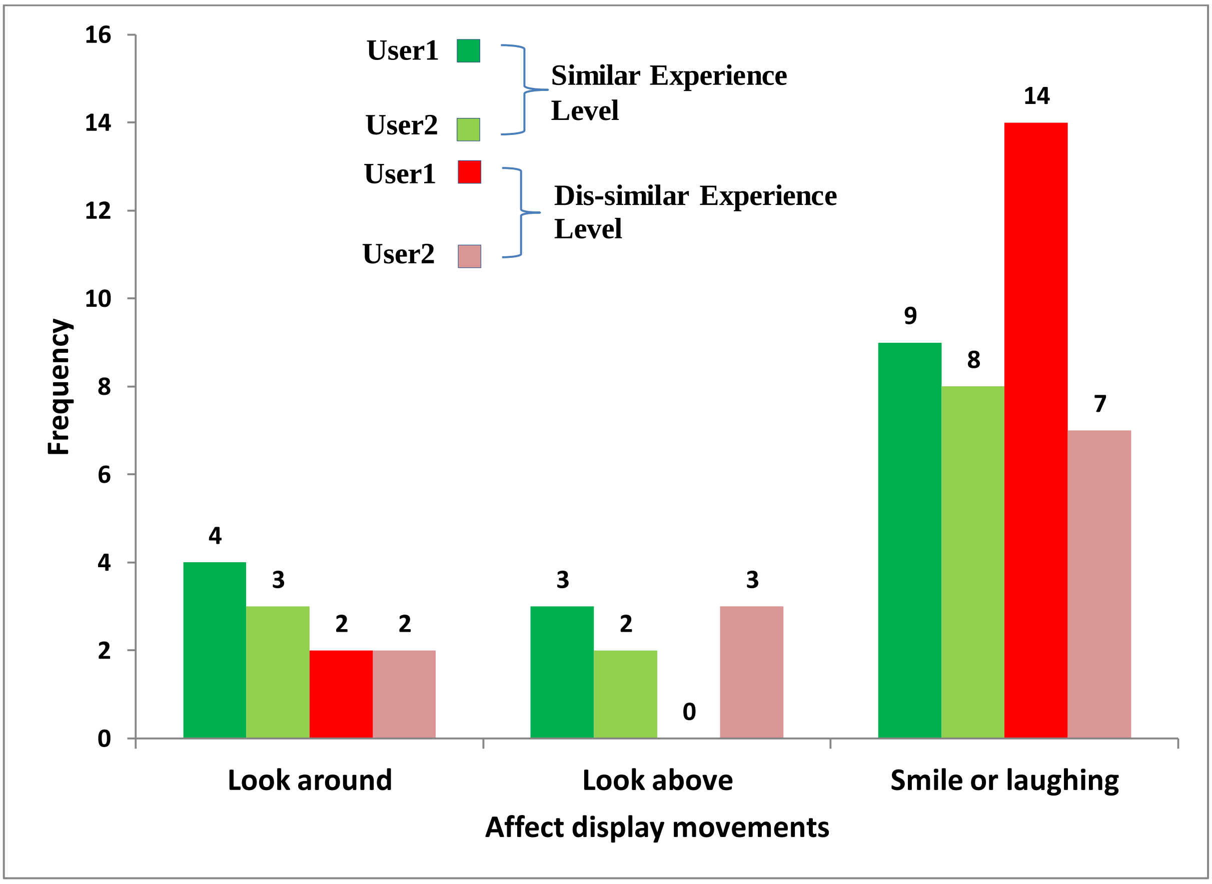


Figure 8.10: Distribution of type of "Affect display" movements for different users

8.8 Summary

An empirically based study of the nature and impact some of NVC components for people who are collaborating on a typical construction industry design task has been undertaken. The results presented are averages for a reasonably large number of experiments and hence are acceptably robust. The manner in which the experiments have been conducted is rigorous and care has been taken to make them as scientifically valid as possible.

1. The analysis of the results for the 20 experiments resulted in the identification of two clear categories of behaviour according to similarity of experience level. There were no significant differences in the number of NVC movements between the users in teams where the members are of similar experience (Category A, 8 experiments, see Fig. 8.1). Conversely, there is a very big difference in the number of NVC movements when the users making up a team have different levels of experience (Category B, 12 experiments), directly resulting in the more experienced user dominating the execution of the task.
2. All users exhibited more illustrator and adaptor movements than other type of movements.
3. There is a relationship between the verbal and non-verbal communication. In Category A, User1 spoke only about 8% more words than User2 and at the same time, there were no significant differences between them in NVC movements. For Category B, User1 spoke about twice as much as User2, and there were also significant differences in NVC movements between them.
4. For all users, about half of the illustrator movements come from the action of staring at/intensive study of an object. From observation of the distribution of productivity and the number of NVC movements over time, there was good justification to see the collaboration as a progression over four phases of work ("initial study", "main production time", "distraction, lull, disagreement" and "final push", see e.g. Fig. 8.3).
5. For all teams, there is close correspondence between the level of productivity and the amount of illustrator movements over the whole of the seven time-periods in each 35-minutes experiment. It is clear illustrator movements are desirable for good team productivity.

6. The pattern for adaptor movements was similar to illustrator movements: both users have similar number in Category A, but User1 used about twice the number of movements compared to User2 in category B. The main actions found were “changing position on chair” (principally by User1 in Category B), “hand on chin, cheek and forehead”, and “vertical head nod”. Similarly, as for illustrator movements, there is also a close correspondence between the level of productivity and the number of adaptor movements over the different time-periods in each experiment, showing that adaptor movements are also useful in achieving good productivity.
7. Conversely, regulator movements correlated negatively with productivity, where the main action was “using hand to interrupt of the other speaker”. Both users displayed similar amount of regulator movements in Category A, but User1 showed just over three times more regulator movements than User2 in Category B.

Chapter 9

Conclusions and Recommendations

9.1 Introduction

This research investigates the differences between FTF and CMC communication for two participants-undertaking a task involving the collaborative amendment of a design of a building. The work examines many points in depth that have not been previously been studied in this context, including quantitative and qualitative measurements of communication, and their relationship to team performance. This chapter presents the principal conclusions of this work as well as suggestions for future studies. The conclusions specifically only apply to the chosen task type and number of participants. Any attempt to extrapolate the results to other situations should be undertaken with extreme caution.

9.2 Summary of Conclusions

The work conducted can be presented under several topics according to the objectives in the chapter one, and thus the conclusions below are presented under these headings.

9.2.1 Communication quantity, time consumed and behaviour profiles

There are three points considered in this objective as the following:-

9.2.1.1 Communication Quantity (total number of words):-

- The work shows the total number of words spoken by the users in FTF is higher (by ≈19%) than for CMC. An analysis of the results show that, this is because the use of social, non-task related communication was higher for FTF. This conclusion is consistent with the work of Kaushik et al. (2000) (see Section 2.4.1). The lower amount of social communication in CMC indicates that this form of collaboration leads to a more task focused approach.
- For FTF, there can be significant differences in the number of words spoken by the two users in a given group. This difference was less noticeable for CMC. The results indicate that, in FTF, the person who spoke most was more dominant in the design process. This contrasts with CMC, where there is less difference between the two participants, indicating that the absence of FTF communication leads to a

more equal form of participation, this conclusion being consistent with the work of Rice & Markey (2009) (see Section 2.8.2). This finding is further reinforced by the results for words articulated emphatically or softly.

- The average speech rate for users in CMC is less than for FTF. Also, the difference between the two users in each group is less in CMC. The reasons for appear to be the additional overhead imposed by the design and communication software in CMC, although this finding has not been conclusively proved.

9.2.1.2 Time Consumed:-

- The time spent on the task, i.e. working time, is slightly higher in CMC than FTF. This ties in with the above findings in the previous section with regard to FTF inducing more social communication. Furthermore, there are some significant differences for working time between the two users in each group when working using FTF but for CMC the difference is small. This ties in with the above conclusion about CMC leading to less dominant participation than FTF.
- The amount of wasted time in FTF is higher than for CMC largely due to users in FTF spending time on social communication (i.e. non-work related words), this representing the main source for wasted time.
- Non-specific time was found to be higher in CMC. In FTF, the major part of this time has been found to wasted time but, in CMC, it is distributed evenly between wasted and working time.

9.2.1.3 Behaviour Profiles:-

- The effect of emotional factors on user behaviour is greater in FTF than in CMC, this conclusion agrees with the work of Riordan & Kreuz (2010) (see Section 2.8.2) and ties in with the above findings on there being a greater level of social communication in FTF.
- The positive emotion factor is better for User2 in CMC than it is in FTF, which indicates that the more submissive team member became more positive. This ties in with the above conclusions on the greater level of dominant behaviour in FTF.

- Likewise the negative emotion factor improved for both users in CMC, indicating a better relationship between the users.

9.2.2 Productivity

- The results clearly show that, for most types of team, the team productivity score is higher in CMC than FTF. This indicates that CMC provides a good environment for collaborative work which increases team productivity. Although the current results are not directly comparable with literature because the task is different, team sizes are different and so on, however the conclusion has agreement with the work of Bordia (1997) (see Section 2.4.3.1), and with the work of Hewage et al. (2008) (see Section 2.5), but it is in contrast with work of Barkhi et al., (1999) (see Section 2.4.1).
- The level of expertise for a team is the primary factor affecting team productivity with greater levels of expertise leading to greater productivity. This conclusion is in agreement with the work of Kavakli et al. (1999) (see Section 2.8.1), with emotions being a secondary factor. Cultural differences and prior relationships of team members also appeared to have an effect on team productivity (i.e. could be positive or negative), but inadequate sample size limits the validity of the results.
- Positive emotions for the teams correlate positively with team productivity (to the same degree in both FTF and CMC); this indicates when the total positive emotions score increases team productivity increases. This conclusion concurs with the work of Feyerherm & Rice (2002) (see Section 2.8.2) while negative emotions correlate negatively with team productivity (with a slightly stronger correlation in FTF). This indicates that a high score for negative emotions means a low level of productivity. This conclusion is consistent with the work of McColl-Kennedy & Anderson (2002) (see Section 2.8.2). There was no relationship between the neutral emotions and team productivity.
- There is a positive correlation between team productivity and:-

  The total number of work-related words, this indicates that more work related words leads to increase in productivity,

  The number of exchanges, this indicates when the degree of collaboration increases team productivity increase; and

Working time.

These correlations were all found to be of equal extent in FTF and in CMC.

- There is a negative correlation between team productivity and wasted time, which is the same extent in both FTF and CMC. This indicates, as one would expect, that when the users waste their time team productivity decreases.
- Team productivity was higher than single-user productivity for the same task. Intuitively, one would say that a single person, working on a task would perform at a high level because the need to spend time communicating with a partner is absent. This result disproves that and shows that there can be benefits to collaboration, possibly because it induces a greater focus on the task.

9.2.3 Degree of Collaboration

- The number of exchanges has been found to be the best indicator of the degree of collaboration for this work.
- The degree of collaboration is higher in CMC than in FTF. This also supports the above findings about dominance being less in CMC.
- There was a positive relationship between the degree of collaboration and the level of team expertise, which was nearly to the same extent in both FTF and CMC. This conclusion is consistent with the work of Jain (2010) (see Section 2.8.1). This indicates when a team has expert users the degree of collaboration between them is high and from the above results it can be seen that this leads to an increase in team productivity.
- Positive emotions for the teams correlate positively with the degree of collaboration (which was slightly higher in CMC). The result indicates that when the score of positive emotions increases, it creates a cooperative environment and this leads to increase interaction between the team members. Conversely, negative emotions correlate negatively with the degree of collaboration (to the same extent in both CMC and FTF), and indicates also when the negative emotions score increases, the interaction between the users decreases, producing a lower degree of collaboration. There is no discernable relationship between neutral emotions and degree of collaboration.

9.2.4 Design Quality.

- The average design quality for CMC is slightly higher than FTF.
- Positive emotions for the teams correlate positively with design quality (which is slightly higher in CMC), i.e. when the total positive emotions score increases design quality increases. This result supports the above results for relationship between positive emotions and productivity and degree of collaboration. Negative emotions correlate negatively with design quality (to the same extent in both CMC and FTF), showing that, when the total negative emotions score increases the design quality decreases. There is no relationship between the neutral emotions and design quality.
- There is a positive correlation between the team design quality and:

  Team expertise level, this conclusion being consistent with the work of Baigent (2000) (see Section 2.10.1). This finding indicates that when the users have good experience in design, this leads to an increase in design quality;

  Team productivity, this indicates that productive teams also had good design quality;

  Degree of collaboration for the team, this indicates that when the users have a good degree of collaboration; it leads to good design quality.

  These relationships were all similar in both FTF and CMC.
- Team design quality was higher than single-user design quality for the same task. This indicates that the users got a good design quality score when they worked as a team and the collaboration process helps them to exchanges their ideas and have taken good decisions about quality.

9.2.5 Non-verbal Communication in FTF

- For teams with members of similar expertise level, the results for non-verbal movements (i.e. illustrators, regulators, adaptors and affect display) were distributed between them, indicating that both users were effectively equal in terms of status and dominance. This ties in with and supports the above conclusions.

- For teams with members of dis-similar expertise levels, User1 was higher than User2 in all non-verbal communication movements. This shows the greater level of dominance of User1. Given that who became User1 and User2 was a choice made by the participants, this is any interesting finding showing that the dominance starts at the very early stages of the process and continues thereafter.
- There was evidence of a relationship between the amount of verbal and non-verbal communication. For teams with members of similar level experience, the difference in number of words spoken between the two users was very small and there are no significant differences between their non-verbal communication movements (Fig. 8.1). Conversely, for the other teams (i.e. dis-similar expertise), there is a big differences in verbal communication between the users accompanied with big differences in non-verbal movements.
- There is a positive relationship between illustrator and adaptor movements and team productivity and, a negative relationship between regulator movements and team productivity, indicating that some types of non-verbal movements such as illustrators and adaptors increase team productivity while other type of movements such as regulators decreases team productivity.

Overall, CMC clearly leads to more equal forms of participation between the users and this occurs in several ways: through the words spoken, the time consumed etc. This equality of participations means CMC reduces the effect of emotional factors on the users and decreases the level of dominant behaviour; this leads to increased team productivity, degree of collaboration and design quality. Also, in CMC the users concentrated more efficiently on their work than those in FTF, this being characterised by a higher level of social conversation between the users.

The findings are of significance for collaborative work in terms of productivity and design quality. Team productivity and design quality were higher than single user productivity. The collaborative work of the team members produced better results than the individuals. As regards the factors affecting team productivity, the level of expertise was clearly the basic factor affecting the productivity score, with emotional factors having a lesser effect. However, the effect of cultural differences and prior relationships is unclear because of the limited sample sizes.

The degree of collaboration in CMC is better than with FTF and the number of exchanges is the best indicator for this degree. Finally, in non-verbal communication movements, some movements increased team productivity, such as those of the illustrator and adaptor, while the regulators movements resulted in reduced team productivity.

9.3 Recommendations for Future Work

Considerable future studies could be conducted to in areas which the present work does not cover.

- The current work only covers communication between two participants. Further studies involving greater number of participants are needed.
- The task in the current work is very narrowly defined, and specific to use of CAD software (Revit). Different, or more complex, or more realistic, or a wider range of tasks could be explored.
- A larger sample of teams could be tested, to then allow better evaluation of effects such as cultural/gender differences, prior relationships, etc on team performance in terms of productivity, degree of collaboration and design quality, etc.
- Explore the work at other construction stages such as the implementation stage, which would require different types of collaboration as well as a greater number of participants and more complexity.
- Study non-verbal communication in CMC by using advanced monitoring tools, especially more cameras with higher definition (for communication as well as for recording), and motion capture devices.
- The current work focussed on one Revit model only. A real life construction project can consist of several Revit models which “interact” with each other within one project. Collaboration could also be evaluated on such simultaneous multi-team multi-model problems using, for example, the “linked model” facility in Revit.
- The emotional profiling work on team members has been rather limited, and only one representative profile is made of a user in the whole of one experiment. Further work could be done with, for example, more dynamic profiling. Further

studies could also then be conducted on team selection based on members' emotional profiles, to optimise team collaboration and productivity.

References

References

Abdul-Gader, A., 1996. The impact of user satisfaction on computer-mediated communication acceptance: A causal path model. *Information Research Management Journal*, Vol. 9, pp. 17-26.

Abolnour, M. M., 1994. The relationship of fee structure in engineering offices and design deficiency, MSc. Dissertation, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Aboudan, R. & Beattie, G., 1996. Cross-cultural similarities in gestures: The deep relationship between gestures and speech which transcends language barriers. *Semiotica*, Vol. 111(3/4), pp. 269-294.

Adams, K. & Galanes, G., 2009. Communicating in groups: Application and skills. 6th ed. New York: McGraw Hill.

Akgün, A. E., Keskina, H. & Byrne, J., 2009. Organizational emotional capability, product and process innovation, and firm performance: An empirical analysis. *Journal of Engineering and Technology*, Vol. 26(3), pp. 103-130.

Akintola, A., McIntosh, G. & Fitzgerald, E., 2000. A survey of supply chain collaboration and management in the UK construction industry. *European Journal of Purchasing & Supply Management,* Vol. 6, pp. 159-168.

Alaghbandrad, A., Nobakth, M. B., Hosseinalipour, M. & Asnaashari, E., 2011. ICT adoption in the Iranian construction industry: Barriers and opportunities. In: Proceeding of 28th International Association for Automation and Robotics in Construction. Seoul, 29 June to 2 July, Korea.

Alel, M., Kwan, A. & Miles, J., 2010. Gains and losses of information when collaborating remotely over a network communication in the construction industry. In: Tizani, W. (ed), Computing in Civil & Building Engineering, Proc. ICCCBE XVII, Nottingham, UK, p. 6.

Alliger, G. M. & Williams, K. J., 1993. Using signal-contingent experience sampling methodology to study work in the field: A discussion and illustration examining task perceptions and mood. *Personnel Psychology*, Vol. 46(3), pp. 525-549.

Amabile, T. M., Patterson, C., Mueller, J., Wojcik, T., Odomirok, P. W. & Marsh, M., 2001. Academic-practitioner collaboration in management research: A case of cross-profession collaboration. *The Academy of Management Journal*, Vol. 44(2), pp. 418-431.

Amaram, D. I., 2007. Cultural diversity: Implications for work place management. *Journal of Diversity Management*, Vol. 2(4). pp. 1-6.

Amason, A. C., 1996. Distinguishing the effects of functional and dysfunctional conflict on strategic decision making: Resolving a paradox of top management teams. *Academy of Management Journal*, Vol. 39(1), pp. 123– 148.

Amiri, A., (2002). An integrated approach for planning the adoption of client/server system. *European Journal of Operational Research*, Vol. 142(3), pp. 509-522.

Andi, S. & Minato, T., 2003. Design documents quality in the japans construction industry: Factors influencing and impacts on construction process. *International Journal of Project Management*, Vol. 21(7), pp. 537-546.

An, Y. & Frick, T., 2006. Student perceptions of asynchronous computer-mediated communication in face to face courses. *Journal of Computer-Mediated communication*. Vol. 11(2), pp. 485-499.

Argyle, M., 1975. Bodily communication. New York: International Universities Press, Inc.

Autodesk Revit Architecture, 2010. Available at: http://images.autodesk.com/adsk/filles/revit_architecture_2010_brochure.pdf. [Accessed July 2009].

Axtell, R. E., 1993. The bestselling guide to international behaviour. 3rd ed. New York: John Wiley and Sons, Inc.

Baiden, B. K., Price, A. D. F. & Dainty, A. R. J., 2006. The extent of team integration within construction project. *International Journal of Project Management*, Vol. 24(1), pp.13-23.

Baigent, A., 2000. Engineers, documentation and litigation, AISC-IEAust Special Issue. *Steel Construction*, Vol. 34(4).

Baker, D. P., Day, R. & Salas, E., 2006. Teamwork as essential components of high-reliability organization. *Health Services Research*, Vol. 41(4), p. 1576-1598.

Balthazard, P. A., Potter, R. E. & Warren, J., 2002. The effects of extraversion and expertise on virtual team interaction and performance. In: Proceedings of the 35th Hawaii International Conference on System Sciences. Big Island, 7-10 January, Honolulu, Hawaii.

Bannon, L. J., 1991. From human factors to human actors: The role of psychology and human computer interaction studies in system design. In: Greenbaum, J, A.M, K. (ed.). Design at Work: Cooperative Design of Computer System. Erlbaum, Hillsdale, pp. 25-44.

Barkhi, R., Jacob, V. & Pirkul, H., 1999. An experimental analysis of face to face versus computer mediated communication channels. *Group Decision and Negotiation*, Vol. 8 (4). pp. 325-347.

Barratt, M. & Oliveira, A., 2001. Exploring the experiences of collaborative planning initiatives. *International Journal of Physical Distribution & Logistics Management*, Vol. 31(4), pp. 266-289.

Barrick, M. R., Stewart, G. L., Neubert, M. J. & Mount, M. K., 1998. Relating member ability and personality to work-team processes and team effectiveness. *Journal of Applied Psychology*, Vol. 83(3), 377–391.

Bettenhausen, K. L., 1991. Five years of group research: What we have learned and what needs to be addressed. *Journal of Management*, Vol. 17(2), pp. 345-381.

Bhappu, A. D. & Crews, J. M., 2005. The effect of communication media and conflict on team identification in diverse groups. In: Proceeding of 38th Hawaii international conference on system science. Big Island, 3-6 January, Los Alamitos, California.

Bishop, J., 1978. The appraisal of building: A case study and critique of approaches. Bristol: University of Bristol Press.

Body language, 2010. Body language guide to reading body language signs and gestures-non-verbal communication. Available at: http://www.businessballs.com/bodylanguage.htm#arms-body-language [Accessed 21April 2010].

Bordia, P., 1997. Face-to-face versus computer-mediated communication: A synthesis of the experimental literature. *Journal of Business Communication*, Vol. 34(1), pp. 99–120.

Bos, N., Olson, J. S., Gergle, D., Olson, G. M. & Wright, Z., 2002. Effect of four computers-mediated communications channels on trust development. In: Proceeding of ACM Conference on Human Factors in Computing (CHI 2002), New York: ACM press, pp.135-140.

Bresnen, M. & Marshall, N., 2000. Partnering in construction: A critical review of issues, problems and dilemmas. *Construction Management. Economic,* Vol. 18(2), pp. 229-237.

Brody, L. R. & Hall, J. A., 2000. Gender, emotion, and expression. In M. Lewis & J. Havilland-Jones (eds.) Handbook of emotions. 2nd ed. pp. 338-349. New York: Guilford Press.

Burait, J. L., Farrington, J. J. & Bedbetter, W. B., 1992. Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management, ASCE*, Vol. 118(1), pp. 34-49.

Butt, N. M., 2011. Impact of non-verbal communication on student's learning outcomes, PhD. Thesis, Sarhad University of Science and Information Technology, Peshawar-Pakistan.

Castro-Lacouture, D. & Ramkrishnan, K., 2008. Fuzzy logic method for measuring building quality. *Journal of Quality,* Vol. 15(2), pp. 117-129.

Chafe, W., 1980. The deployment of consciousness in the production of narrative. In: W. Chafe (ed.), the pear stories: Cultural, cognitive, and linguistic aspects of narrative production (pp. 9-50). Norwood, New Jersey: Ablex.

Chen, H. M., Tien, H. C., 2007. Application of peer-to-peer network for real time online collaborative computer-aided design. *Journal of Computing in Civil Engineering*, Vol. 21(2), pp. 112-121.

Cohen, A. & Scardamalia, M., 1998. Discourse about ideas: Monitoring and regulation in face-to-face and computer-mediated environments. *Interactive Learning Environments*, Vol. 6(1-2), pp. 93–113.

Cochran, W. G. & Gertrude, M. C., 1992. Experimental Designs. 2nd ed. New York: John Wiley & Sons.

Cowie, R., Douglas, E., Tsapatsoulis, N., Votsis, G., Kollias, S., Fellenz, W. & Taylor, J. C., 2001. Emotion recognition in human computer interaction. *IEEE Signal Processing Magazine*, Vol. 18(1), pp.32-80.

Cramton, C. D. M., 2001. The mutual knowledge problem and its consequences for dispersed collaboration. *Organization Science*, Vol. 12(3), pp. 346-371.

Creswell, J. W., 2005. Educational research: Planning, conducting and evaluating quantitative and qualitative research .2nd ed. Upper Saddle River, N.J.: Person Merrill, Prentice-Hall.

Cross, N. & Cross, A., 1995. Observations of teamwork and social processes in design. *Design Studies*, Vol. 16(2), pp. 143-170.

Curhan, J. R., 2007. Thin slices of negotiation: Predicting outcomes from conversational dynamics within the first 5 minutes. *Journal of Applied Psychology*, Vol. 92(3), pp. 802-811.

Dainty, A., Moore, D. & Murray, M., 2006. Communication in construction: Theory and practice. Oxford, UK: Taylor & Francis.

Dancey, C. P., & Reidy, J., 2004. Statistic without maths for psychology: And psychology dictionary, 3rd ed. Edinburgh Gate, England: Pearson Education Limited.

David, S. M., 2000. The basic practice of statistics. 2nd ed. New York: W.H. Freeman and Company.

Dawood, N., Akinsola, A. & Brian, H., 2002. Development of automated communication of system for managing site information using internet technology. *Automation in Construction*, Vol. 11(5), pp. 557-572.

Delarue, A., Stijn, G. & Van Hootegem, G., 2003. Productivity outcomes of teamwork as an effect of team structure, working paper, Steunpunt OOI, Catholic University of Leuven. Available at: http://www.ondernemerschap.be/documents/pdf/wp_productivity_outcomes_of_teamwork .df

Deng, Z. M., Li, H., Tam, C. M., Shen, Q. P. & Love, P. E. D., 2001. An application of the internet-based project management system. *Automation in Construction*, Vol. 10(2), pp. 239-246.

De Waal, F. B. M., 2003. Darwin's legacy and the study of primate visual communication. In P. Ekman, J. campos, R. J. Davidson & F. B. M. De Waal (eds.), Emotions inside out: 130 years after Darwin's. The expression of Emotion in Man and Animals, pp. 7-31. New York: New York Academy of Sciences.

Dietz-Bhler, B. & Bishop-Clark, C., 2001. The use of computer-mediated communication to enhance subsequent face to face discussions. *Computer in Human Behaviour*, Vol.17, pp. 269-283.

Dyer, C., 2006. Research in psychology: A practical guide to methods and statistics. Malden MA, USA: Blackwell Publishing.

Dzambazova, T., Krygiel, E. & Demchak, G., 2010. Introducing Revit Architecture 2010 BIM for beginners. Indianapolis, USA: Wiley Publishing, Inc.

Edwards, L. D., Coddington, A. & Caterina, D., 1997. Girls teach themselves and boys too: Peer learning in a computer-based design and construction activity. *Computers Education,* Vol. 29(1), pp. 33-48.

Efron, D., 1941. Gesture and environment. Morningside heights, New York: King's Crown Press. Republished as gesture, race and culture. The Hague, the Netherlands: Mouton.

Egan, J., 1998. Rethinking construction. Department of the environment, transport and the regions, London. Emmitt, S., architectural management-an evolving field, Engineering. *Construction and Architectural Management*, Vol. 6(2), pp. 188–196.

Egbu, C., Gaskell, C. & Howes, J., 2001. The role of organization culture and motivation in the effective utilization of information technology for teamworking in construction. *Research in Construction Management*, Vol. 1, pp. 91-100.

Ehsan, N., Mirza, E. & Ahamed, M., 2008. Impact of computer-mediated communication on virtual teams' performance: An empirical study. *World Academy of Science, Engineering and Technology*, Vol. 42, pp. 694-703.

Ekman, P. & Friesen, W. V., 1969. The repertoire of nonverbal behaviour: Categories, origins, usage and coding. *Semiotica,* Vol. 1, pp. 49-98.

Ekman, P., Friesen, W. V. & Ellsworth, P., 1972. Emotion in the human face: Guidelines for research and integration of findings. New York: Pergamum press.

Ekman, P. & Friesen, W. V., 1978. Facial action coding system: A technique for the measurement of facial movement. Palo Alto, Calif.: Consulting Psychologists Press.

Ekman, P., 1984. Expression and the nature of emotion. In K. Scherer and P. Ekman (eds.), approaches to emotion, pp. 319-343. Hillsdale, N.J: Lawrence Erlbaum.

Ekman, P., 1993. Facial expression and emotion. *American Psychologist,* Vol. 48(10), pp. 384-392.

Ekman, P., 1997. Should we call it expression or communication?. *European Journal of Social Sciences*, Vol. 10(4), pp 333-359.

Ellis, A. P. J., Bell, B. S., Ployhart, R. E., Hollenbeck, J. R. & Ilgen, D. R., 2005. An evaluation of generic teamwork skills training with action team: Effect on cognitive and skill-based outcomes. *Personnel Psychology*, Vol. 58(3), pp. 641-672.

English, A., Griffith, R. L. & Steelman, L. A., 2004. Team performance: The effect of team conscientiousness and task type. *Small Group Research*, Vol. 35(6), pp. 643-665.

Ertmer, P. A. & Stepich, D. A., 2005. Instructional design expertise: How will we know it when we see it?. *Educational technology*, Vol. 45(6), pp. 38-43.

Facial expression meaning: Available at: http://www.youramazingbrain.org.uk/asp/signup.asp?surveyname=bodylanguage3 [Accessed 6 June 2012].

Faraj, I., Alshawi, M., Aouad, G., Child, T. & Underwood, J., 2000. An industry foundation classes web-based collaborative construction computer environment: WISPER. *Automation in Construction*, Vol. 10, pp. 79-99.

Feyerherm, A. E. & Rice, C. L., 2002. Emotional intelligence and team performance: The good, the bad and the ugly. *International Journal of Organizational Analysis,* Vol. 10(4), pp. 343-362.

Frank, M. G., 1997. Some thoughts on FACS, dynamic markers of emotion, and baseball. In P. Ekman & E. L. Rosenberg (ed.), what the face reveals: Basic and applied studies of spontaneous expression using the facial action coding system (FACS), pp. 239-242, New York: Oxford University press.

Fruchter, R., 1998. Internet Web-mediated collaborative design and learning environment. *Artificial Intelligence in Structural Engineering,* Vol. 26, pp. 384-397.

Gann, D. M., Salter, A. G & Whyte, J. K., 2003. Design quality indicator as a tool for thinking. *Building Research and Information*, Vol. 31(5), pp.318-333.

Garza, V., 2001. Online learning in accounting education: A study of compensatory adaptation, PhD. Thesis, Texas A & M International University, Concentration: Management Information Systems, USA.

Gauthier, T. D., 2001. Detecting trends using spearman's rank correlation coefficient. *Environmental Forensics,* Vol.2, pp.359-362.

George, J. M. & Bettenhausen, K., 1990. Understanding prosocial behaviour, sales performance, and turnover: A Group-level analysis in a service context. *Journal of Applied Psychology*, Vol. 75(6), pp. 698-709.

Gergle, D., Millan, D. R., Kraut, R. E. & Fussell, S. R., 2004. Persistence matters: Making the most of chat in Tightly-coupled work. In: Proceedings of the Conference on Human Factors in Computing Systems. Austria, 24-29 April, pp. 431-438.

Gifford, R., Hine, D., Muller-Clemm, W., Reynolda, D. J. & Shaw, K., 2000. Decoding modern architecture: A lens model approach for understanding the aesthetic differences of architects and laypersons. *Environment and Behaviour*, Vol. 32, pp. 163-187.

Goffman, E., 1959. The presentation of self in everyday life. Re printed in Hartmondsworth: Penguin books (1990).

Gopal, A., Mirana, S. M., Robichaux, B. P. & Bostrom, R. P., 1997. Leveraging diversity with information technology: Gender, attitude, and intervening influences in the use of group support system. *Small Group Research*, Vol. 28, pp. 29-71.

Griffith, A. & Sidwell, A. C., 1995. Constructability in building and engineering projects. London: Macmillan Press Ltd.

Gruenfeld, D. H., Mannix, E. A., Williams, K. Y. & Neale, M. A., 1996. Group composition and decision making: How member familiarity and information distribution affect process and performance. *Organizational Behaviour and Human Decision Processes*, Vol. 67(1), pp. 1-15.

Gray, C. & Moffett, J., 2010. Handbook of veterinary communication skills. UK: Blackwell Publishing Ltd.

Guye-Vuilleme, A., Capin, T. K., Pandzic, I. S., Thalmann, N. M. & Thalmann, D., 1999. Nonverbal communication interface for collaborative virtual environments. *Virtual Reality Journal*, *Springer*, Vol. 4(1), pp. 49-59.

Guzzo, R. A. & Shea, G. P., 1992. Group performance and intergroup relation in organization. *Handbook of Industrial and Organizational Psychology*, Vol. 3, pp. 269-313.

Halfway, M. & Froese, T., 2004. Component-based framework for implementing integrated architecture-engineering-construction project system. *Journal of Computing in Civil Engineering*, Vol. 21(6), pp. 441-452.

Hall, E. T., 1984. The dance of life: The other dimension of time. Garden City, New York: Anchor press/ Doubleday.

Hall, J. A., 1984. Non-verbal difference: Communication accuracy and expressive style. Baltimore, MD: Johns Hopkins University Press.

Hambrick, D. C., Davison, S. C., Snell, S. A. & Snow, C. C., 1998. When groups consist of multiple nationalities: Towards a new understanding of the implications. *Organization Studies,* Vol. 19(2), pp. 181–205.

Hancock, J. T. & Dunham, P. J., 2001. Impression formation in computer-mediated communication revisited: A analysis of the breadth and intensity of impressions. *Communication Research*, Vol. 28(3), pp. 325-347.

Harasim, L., 1986. Computer learning networks: Educational applications of computer conferencing. *Journal of Distance Education*, Vol.1 (1), pp. 59-70.

Hare, A. P., 2003. Roles, relationships and group in organizations: Some conclusion and recommendations. *International Journal of Small Group Research*, Vol. 34(2), pp.123-154.

Hassell, J., 2006. Learning windows server 2003. 2nd ed. Gravenstein Highway North, USA: O'REILLY Media, Inc.

Hartmann, T., Fischer, M. & Haymaker, J., 2009. Implementing information system with project teams using ethnographic-action research. *Advanced Engineering Informatics*, Vol. 23(1), pp.57-67.

Hatem, W. A., Kwan, A. & Miles, J., 2011. A comparison of face to face and computer mediated collaboration. In: Proceeding of International workshop of European Group for Intelligent Computing in Engineering, EG-ICE 2011, Twente University, 4-7 July, Netherlands.

Hatem, W. A., Kwan, A. & Miles, J., 2012. Comparing the effectiveness of face to face and computer mediated collaboration. *Advanced Engineering Informatics*, doi:10.1016/j.aei.2012.01.001.

Hegazy, T., Zeneldin, E. & Grierson, D., 2001. Improving design coordination for building projects: Information model. *Journal of Construction Engineering and Management, ASCE,* Vol. 127(4), pp. 322-329.

Herring, S., 2003. Computer-mediated discourse. In: Deborah Schiffrin, Deborah Tannen and Heidi E. Hamilton (ed.), pp. 612-634. The handbook of discourse analysis. Oxford: Blackwell.

Hewage, K. N., Ruwanpura, J. Y. & Jergeas, G. F, 2008. IT usage in Alberta's building construction project: Current status and challenges. *Automation in Construction*, Vol. 17(8), pp. 940-947.

Heywood, J. S. & Jirjahn, U., 2004. Teams, teamwork and absence. *Scandinavian Journal of Economics* Vol. 106(4), pp. 765-782.

Hincks, R., 2009. Speaking rate and information content in English lingua franca oral presentations. *English for Specific Purposes.* Vol. 29(1), pp. 4-18.

Hollingshead, A. B., McGrath, J. E. & O'Connor, K. M., 1993. Group task performance and communication technology: A longitudinal study of computer-mediated versus face-to-face work groups. *Small Group Research,* Vol. 24(3), pp. 307-333.

Holzer, D., 2007. Are you talking to me? BIM alone is not the answer. Royal Melbourn of Technology, Association of Architecture School Australasia, Conference 2007. Available at:http://epress.lib.uts.edu.au/ocs/index.php/AASA/2007/paper/viewFile. [Accessed 5 June 2012].

Howell, I., 1996. The need for interoperability in the construction industry. In: Proceeding of the INCIT 96 International Construction Information Technology Conference. Sydney, 18-19 April, Australia, pp. 43-47.

Huckman, R. S., Staats, B. R. & Upton, D. M., 2009. Team familiarity, role experience, and performance: Evidence from Indian software services. *Management Science,* Vol. 55(1), pp. 85-100.

Hung-Wen, H., Hsien-Jung, W. & Hsing-Chung, K., 2010. A CMC- based design communication for collaborative design project. *Asian Journal Arts and Science,* Vol. 1(1), pp. 1-16.

Iles, P. & Hayers, P. K., 1997. Managing diversity in transnational project teams: A tentative model and case study. *Journal of Managerial Psychology,* Vol. 12(2), pp. 95-117.

Imai, G., 1996. Gestures: Body Language and nonverbal communication. Retrieved Oct, 2005, from California State Polytechnic University: Available at: http://www.internet .csupomona.edu?tassi/gestures.htm. [Accessed 4 June 2012].

Jain, A., 2010. Learning by doing and the locus of innovative capability in biotechnology research: Opening up innovation strategy, organization and technology: Paper presented in summer conference, Imperial Collage London, Business school, London.

Jeffrey, W., Lui, M., Jiazhi, O., Carolyn, P. R., Jie, Y., Susan, R. & Fussell, S. R., 2007. Sharing a single expert among multiple partners. In: proceeding of the SIGCHI Conference of Human Factors in Computing System (CHI), New York, 22-27 April, USA, pp. 261-270.

Jehn, K. A. & Shah, P. P., 1997. Interpersonal relationships and task performance: An examination of mediating processes in friendship and acquaintance groups. *Journal of Personality and Social Psychology,* Vol. 72(4), pp. 775-790.

Jessup, L. M., Connolly, T. & Tansik, D. A., 1990. Toward a theory of automated group work: The deindi-viduating effects of anonymity. *Small Group Research,* Vol. 21(3), pp. 333–348.

Kallinen, K. & Ravaja, N., 2004. Emotional-related effect of speech rate and rising vs. falling background music melody during audio news: The moderating influence of personality. *Personality and Individual Differences,* Vol. 37(2), pp. 275-288.

Karat, J. & Karart, C. M., 2003. The evolution of user-centered focus in the human-computer interaction field. *IBM System Journal*, Vol. 42(2), pp.532-541.

Karoc-Kakabadse, N. & Kouzmin, A., 2001. Low and high context communication patterns: Towards mapping cross-cultural encounters. *Cross Cultural Management*, Vol. 8(2), pp.3-24.

Katz, R., 1982. The effects of group longevity on project communication and performance. *Administrative Science Quarterly*, Vol. 27(1), pp. 81-104.

Kaushik, R., David, P., Kline, S. & Oaks, D., 2000. Social presence effect: A study of CMC versus FTF in collaboration fiction project. In: Proceeding of the 5th Annual International Workshop, Universidad Fernando Pessoa, 9-11 October Porto, Portugal, pp. 1-28.

Kavakli, M., Suwa, M., Gero, J. S. & Purcell, T., 1999. Sketching interpretation in novice and expert designers. In. Gero, J.S., and Tversky, B (eds), visual and spatial reasoning in design, key centre of design computing and cognition, University of Sydney, Sydney, pp. 209- 219.

Kavakli, M., Gero, J. S., 2002. The structure of concurrent cognitive actions: A case study on novice and expert designers. *Design Studies,* Vol. 23(1), pp. 25-40.

Kelly, H. Z., Kemal, T. & Stuart, G., 2003. Correlation and simple linear regression. *Radiology*, Vol. 227(3), pp.617-628.

Kendon, A., 1994. Do gestures communicate? A review. *Research on Language and Social Interaction*, Vol. 27(3), pp. 175-200.

Keyton, J., 2011. Communication and organization culture: A key to understanding work experience. Thousand Oaks, CA: Sage

Kiesler, S., Siegel, J. & McGuire, T. W., 1984. Social psychological aspects of computer-mediated communication. *American Psychologist,* Vol. 39(10), pp. 1123-1134.

Kimble, C., Hildreth, P. & Wright, P., 2000. "Communities of practice: Going the extra half Mile", in: Knowledge Management and Business Model, Innovation, Idea Group Publishing, Hershey (USA)/ London (UK).

Kleinman, G. & Palmon, D., 2001. Understanding auditor-client relationships: A multi-faceted analysis. Princeton, NJ: Markus Weiner Publishers, Inc.

Knapp, M. L., 1978. Nonverbal communication in human interaction. 2nd ed. New York: Holt, Rinehart and Winston.

Knapp, M. L., & Hall, J. A., 2007. Nonverbal communication in human interaction. 5th ed. Wadsworth: Thomas Learning.

Kopelman, S., Rosette, A. & Thompson, L., 2006. The three faces of Eve: Strategic displays of positive, negative and neutral emotions in negotiations. *Organizational Behaviour and Human Decision Processes,* Vol. 99(1), pp. 81-101.

Kraut, R. E. & Johnston, R. E., 1979. Social and emotional messages of smiling: An ethological approach. *Journal of Personal and Social Psychology,* Vol. 37(9), pp. 1539-1553.

Kumar, J. & Mukherjee, M., 2009. Scope of building information modelling (BMI) in India. *Journal of Engineering Science and Technology Review,* Vol. 2 (1), pp. 165-169.

Kwan, A. Y. & Ofori, G., 2001. Chinese culture and successful implementation of partnering in Singapore's construction industry. *Construction Management and Economics,* Vol. 19(6), pp. 619-632.

Lantz, A., 2001. Meetings in a distributed group of experts: Comparing face-to-face, chat and collaborative virtual environments. *Behaviour and Information Technology,* Vol. 20(2), pp. 111-117.

Larson, C. E., & LaFasto, F. M. J., 1989. Teamwork: What must go right, what can go wrong? Newbury Park, California: Sage publications.

Lawson, B. & Dorst, K., 2009. Design Expertise. Oxford, UK: Architectural Press.

Lee, A. S., Liebenau, J. & Degross, J. I., 1997. Information systems and qualitative research. In: Proceeding of the IFIP TC8 WG 8.2 International Conference on Information System and Qualitative Research. Philadelphia, 31 May to 3 June, Pennsylvania, USA.

Lee, C. E., 2011. Computer-Mediated Communication and Organisational Communication: The Use of New Communication Technology in the Workplace. *The Journal of the South East Asia Research Centre for Communication and Humanities,* Vol. 3, pp.1-12.

Lee, C. E., 2010. Face-to-face versus computer-mediated communication: Exploring employees' preference of effective employee communication channel. *International Journal for the Advancement of Science & Arts,* Vol. 1(2), pp. 28-38.

Lesikar, R. V. & Flatley, M. E., 2005. Basic business communication: Skill for empowering the internet generation. 10th ed. New York: McGraw-Hill.

Lind, M. R., 1999. The gender impact of temporary virtual work groups. *Transactions on Professional Communication*. Vol. 42(2), pp. 276-285.

Likert, R., 1932. A technique for the measurement of attitudes. *Archives of Psychology,* Vol. 140(1), pp. 44-53.

Love, P. E. D., Mandel, P. & Li, H., 1997. A systematic approach to modelling the causes and effects of rework in construction. In: Proceedings of the 1st International Conference on Construction Industry Development: Building the Future Together, Singapore, 4-8 July, Vol. 2, pp. 347-355.

Lutz, J., Hancher, D. & East, E., 1990. Framework for design quality review data-base system. *Journal of Management in Engineering*, Vol. 6(3), pp. 296-312.

Lynn, G. S. & Akgum, A. E., 2003. Launch your new products /services better, faster. *Research Technology Management,* Vol. 46 (3), pp. 21-26.

Mason, R., 2003. Teach yourself. Speaking on special occasions. London: Hodder & Stoughton, p.41.

Matsumoto, D., Yo, S. H., Hirayama, S. & Petrova, G., 2005. Development and validation of a measure of display rule knowledge: The display rule assessment inventory (DRIA). *Emotion*, Vol. 5(1), pp. 23-40.

McColl-Kennedy, J. R. & Anderson, R. D., 2002. Impact of leadership style and emotions on subordinate performance. *The Leadership Quarterly*, Vol. 13(5), pp. 545-559.

McCullouch, B. G., 1996. A decision tool for incorporating construction knowledge during design. In Langford, D.A. & Retik, A. (ed). The organisation and management of construction: Shaping theory and practice, London: E & FN Spon, Vol. 2. pp. 509-518.

McGinn, K. L. & Keros, A. T., 2002. Improvisations and logic of exchange in socially embedded transactions. *Administrative Science Quarterly,* Vol. 47(3), pp. 442-473.

Mchoskey, J., 1995. Narcissism and machiavellianism. *Psychological Reports,* Vol. 77, pp. 755–759.

Mehrabian, A., 1981. Silent message: Implicit communication of emotion and attributes. .2nd ed. Belmont, CA: Wadsworth publishing company.

Mellers, B., Schwartz, A. & Ritov, I., 1999. Emotions-based choice. *Journal of Experimental Psychology,* Vol. 128(3), pp. 332-345.

Miller, P. W., 1998. Nonverbal communication: What a researcher says to the teachers .3rd ed. USA: National Education Association , p. 11.

Miller, K., 2009. Organisational communication: Approaches and process. 5th ed. United States of America: Wadsworth.

Monteverde, K., 1995. Technical dialog as an incentive for vertical integration in the semiconductor industry. *Management Science.* Vol. 41(10), pp. 1624-1638.

Narayanan, S., Balasubramanian, S. & Swaminathan, J. M., 2009. Managing outsourced software projects: An analysis of project performance and customer satisfaction. Production and. Operations Management. Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1548244 [Accessed 11June 2011].

Nohria, N. & Eccles, R., 1998. Network and organisations: Structure, form and action. Boston, USA: Harvard Business School Press.

Nowak, K., Watt, J. H. & Walther, J., 2005. The influence of synchrony and sensory modality on the person perception process in computer mediated groups. *Journal of Computer-Mediated Communication*, Vol. 10(3), article 3.

Ottenheimer, H. J., 2005. The anthropology of language: An introduction to linguistic anthropology. Kanasa State: Thomson Wadsworth.

Peltoniemi, M. & Jokinen, T., 2004. Communication good practices in high technology product development projects: Experiences from a case study. In: Proceedings of the International Cost Engineering Council's 4th World Congress. Cape Town, 17-21 April, RSA, p. 3-4.

Pena-Mora, F., Hussen, k., Vadharkar, S. & Benjamin, K., 2000. A concurrent engineering meeting environment for virtual design team. *Artificial Intelligence in Engineering*, Vol. 14, pp. 203-219.

Pena-Mora, F., Sanjeev, V. & Zeeshan, A., 2009. Technology strategies for globally dispersed construction team. *Journal of Information Technology in Construction*, Vol. 14, pp. 70-80.

Perez, R. S. & Emery, C. D., 1995. Designer thinking: how novices and experts think about instructional design. *Performance Improvement Quarterly*,Vol. 8, pp. 80-95.

Porath, C. L., Overbeck, J. R. & Pearson, C. M., 2008. Picking up the gauntlet: How individuals respond to status challenges. *Journal of Applied Social Psychology*, Vol. 38(7), pp 1945-1980.

Poulton, B. C. & West, M. A., 1999. The determinants of effectiveness in primary health care teams. *Journal of Inter Professional Care*, Vol. 13(1), pp. 7-18.

Pulaski, M. H. & Horman, M. J., 2005. Organising constructability knowledge for design. *Journal of Construction Engineering & Management*, Vol. 131(8), pp. 911-919.

Pyrczak, F., 2002. Success at statistics: A worktest with humor. 2nd ed. Los Angeles: Pyrczak Publishing.

Quambar, S., 1999. A system approach to construction productivity: Unpublished doctoral dissertation, Notting ham University.

Quené, H., 2005. Modeling of between speaker and within speaker variation in spontaneous speech tempo. In: Proceeding of the 9th European Conference Speech Communication and Technology (Interspeech), Lisbon, 26-28 may, Portugal, pp. 2457-2460.

Reagans, R., Argote, L. & Brooks, D., 2005. Individual experience and experience working together: Predicting learning rates from knowing who know what and knowing how to work together. *Management Science*, Vol. 51(6), pp. 869-881.

Revit Architecture User's Guide, 2009. Available at: http://revit.downloads.autodesk.com/download/RAC2009/Documents/ENU/HelpArchitectureENU.pdf. [Accessed July 2009].

Rezgui, Y., 2007. Exploring virtual team-working effectiveness in the construction sector. *Interacting with Computers*, Vol. 19(1), pp. 96-112.

Rice, R. E., 1986. Applying the human relation's perspective to the study of new media. *Computer and Society*, Vol. 15(4), pp. 32-37.

Rice, L. & Markey, P. M., 2009. The role of extraversion and neuroticism in influencing anxiety following computer-mediated interactions. *Personality and Individual Differences*, Vol. 46(1), pp. 35-39.

Riordan, M. A. & Kreuz, R. J., 2010. Emotion encoding and interpretation in computer-mediated communication: Reasons for use. *Computer in Human Behaviour*, Vol. 26(6), pp. 1667-1673.

Riva, G. & Galimberti, C., 1997. The psychology of cyberspace; a social cognitive framework to computer mediated communication. *New Ideas in Psychology*, Vol. 15 (2), pp. 141-158.

Robyn, S., 2005. Broadband videoconferencing as a tool for learner-centred distance learning in higher education. *British Journal Educational Technology*, Vol. 36(5), pp. 805-820.

Rocco, E., 1998. Trust breaks down in electronic contexts but can be repaired by some introductory face-to-face contact. In: Proceedings of the Conference on Human Factors in Computing Systems-CHI'98. Los Angeles, 18-23 April, pp. 496-502.

Roeloelofsen, P., 2002.The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. *Journal of Facilities Management*, Vol. 1(3), pp. 247-264.

Rosen, B., Furst, S. & Blackburn, R., 2007. Overcoming barriers to knowledge sharing in virtual teams. *Organization Dynamics*, Vol. 36(3), pp. 259-273.

Ross, R. S., 1977. Speech communication. 4th ed. New Jersey: Prentice-hell.

Rousseau, V., Aubé, C. & Savoie, A., 2006. Teamwork behaviours: A review and an integration of framework. *Small Group Research*, Vol. 37(5), pp. 540-570.

Rowland, G., 1992. What do instructional designers actually do? An initial investigation of expert practice. *Performance Improvement Quarterly*, Vol. 5(2), pp. 65-86.

Rundell, R., 2007. The five Fallacies of BIM. Available at: http://images.autodesk.com/..../five_fallacies_of_bim_whitepaper_us1.pdf. [Accessed July 2009].

Saavedra, R., Earley, P. C. & VanDyne, L., 1993. Complex interdependence in task performing groups. *Journal of Applied Psychology*, Vol. 78(1), pp. 61-72.

Salas, E., Shawn Burke, C. & Cannon-Bowers, J. A., 2002. Teamwork: Emerging principles. *International Journal of Management Reviews*, Vol. 2(4), pp. 339-356.

Sannie, M. B. A., 2006. Business communication and use of english. 2nd ed. M. B. A, Corporate Word Investment. Lagos Nigeria.

Schalkwyk, J., 2000. Culture gender equality and development cooperation, unpublished paper prepared for Canadian international development agency.

Semar. W., 2005. Development of benchmark system for analyzing collaborative group performance as part of an educational online knowledge management system. In: Proceedings of International Conference on Information and Knowledge Engineering (IKE'05). Las Vegas, 20-23 June: CSREA Press, P. 53-59.

Seymen, O. A., 2006. The cultural adversity phenomenon in organisations and different approaches for effective cultural diversity management: A literary review. *Cross Cultural Management: An International Journal*, Vol. 13(4), pp. 296-315.

Simatupang, T. M. & Sridharan, R., 2004. A benchmarking scheme for supply chain collaboration. *Benchmarking: An International Journal*, Vol. 11 (1), pp. 9-30.

Simatupang, T. M., & Sridharan, R. 2005. The collaboration index: A measure for supply chain collaboration. *International Journal of Physical Distribution & Logistics Management*, Vol. 35(1), pp. 44-62.

Smith, P., 1987. Architecture and the principle of harmony. London: RIBA.

Sniezek, J. A. & Crede, M., 2002. Group judgment processes and outcomes in video-conferencing vs. face-to-face groups. In: Proceeding of the 35th Hawaii International Conference on System Sciences. Big Island, 7-10 January, Honolulu, Hawaii.

Staples, D. S. & Zhao, L., 2006. The effects of cultural diversity in virtual teams versus face-to-face teams. *Group Decision and Negotiation*, Vol. 15(4), pp 389–406.

Straus, S. G. & McGrath, J. E., 1994. Does the medium matter? The interaction of task type and technology on group performance and member reactions. *Journal of Applied Psychology*, Vol. 79(1), pp. 87-97.

Straus, S. G., 1996. Getting a clue: The effects of communication media and information distribution on participation and performance in computer mediated and faces to face groups. *Small Group Research*, Vol. 27(1), pp. 115-140.

Storch, H. & Francis, W.Z., 1999. Statistical analysis in climate research. Cambridge: Cambridge University Press.

Sumi, K. & Moriyama, J., 2010. Analyses of nonverbal behaviour of technology teachers in the classroom. Hyogo University of teacher education, Saga University, Japan. Available at: http://www.iteaconnect.org/Conference/PATT/PATT14/sumi.pdf [Accessed 15 April 2010].

Sze-wing, L., Stephen, M. & Bill, L. P. L., 2008. Using a real-time integrated communication system to monitor the progress and quality of construction works. *Automation in Construction*, Vol. 17, pp. 749-757.

Takao, S., 1999. The effective of narrow-band width multipoint video on group decision making and turn distribution. In: Proceedings of the International Joint Conference on Work Activities Coordination and Collaboration**.** San Francisco, 22-25 February, California, United States, pp. 109-116.

Tam, C. M., 1999. Use of internet to enhance construction communication: Total information transfer system. *International Journal of Project Management*, Vol. 17(2), pp. 107-110.

Tang, H., 2001. Construction for excellence. Report for the construction industry review committee (CIRC), Hong Kong special administrative region government, Hong Kong.

Tang, D., 2004. An agent-based collaborative design system to facilitate active die-maker involvement in stamping part design. *Computers in Industry*, Vol. 54(3), pp. 253-271.

Tannen, D., 1994. Gender and discourse*:* Featuring a new essay on talk at work. New York: Oxford University Press. The Concise Oxford Dictionary, 2001. 9th ed. Oxford University Press, CR-ROM.

Thurlow, C., Lengel, L. & Timic, A., 2004. Computer mediated communication: Social interaction and the internet. Sage Publication: London

Tidwell, L. C. & Walther, J. B., 2002. Computer-mediated communication effects on disclosure, impressions and interpersonal evaluations: Getting to know one another a bit at a time. *Human Communication Research,* Vol. 28(3), pp. 317-348.

Tilley, P. A., McFallan, S. L. & Sinclair, R. G., 2002. Improving design and documentation quality. In, measurement and management of architectural value in performance-based building. In: Proceedings of the CIB W60/W96 Joint Conference on Performance Concept in Building and Architectural Management. Hong Kong, 6-8 May, CIB Publication 283: Rotterdam, pp. 361-377.

Tooby, J., Cosmides, L., 1996. Friendship and the banker’s paradox: Other Pathways to the evolution of adaptations for altruism. *Proceedings of the British Academy*, Vol. 88, pp. 119-143.

Trigunarsyah, B., 2004. A review of current practice in constructability improvement case studies on construction projects in Indonesia. *Construction Management & Economics*, Vol. 22(6), pp. 567-580.

Valacich, J. S. & Sarker, S., 2002. Computer-mediated and face-to-face groups: Who makes riskier decisions? In: Proceedings of the 35th Hawaii International Conference on System Sciences. Big Island, 7-10 January, Honolulu, Hawaii.

Van der Meijden, H. & Veenman, S., 2005. Face to face versus computer-mediated communication in primary school setting. *Computer in Human Behaviour,* Vol. 21(5), pp. 831-859.

Van, L. J. P. & Fridqvist, S., 2006. An information model for collaboration in the construction industry. *Computers in Industry,* Vol. 57, pp. 809-816.

Verhoeven, J., De Pauw, G. & Kloots, H., 2004. Speech rate in pluricentric language. A comparison between Dutch in Belgium and the Netherlands. *Language and Speech,* Vol. 47(3), pp. 297-308.

Ververidis, D. & Kotropoulos, C., 2006. Emotional speech recognition: Resources, features, and methods. *Speech Communication,* Vol. 48(9), pp. 1162-1181.

Vinciarelli, A., 2009. Capturing order in social interactions. *IEEE Signal Processing Magazine,* Vol. 26 (5), pp. 133-137.

Von Glinow, M. A., Shapiro, L. D. & Brett, J. M, 2004. "Can we talk, and should we? Managing emotional conflicts in multicultural teams". *Academy of Management Review,* Vol. 29, pp. 578-592.

Wagner, H. L., 1997. Methods for the study of facial behaviour. In J. A. Russell & J. M. Fernandez-Dols (ed.), The Psychology of facial expression, pp. 31-54.New York: Cambridge University Press.

Wainwright, R. G., 2003. Teach yourself, body language. London: Hodder Headline, p. 21.

Walther, J. B., 1995. Relational aspects of computer-mediated communication: Experimental observations over time. *Journal of Organization Science,* Vol. 6(2), pp. 186-203.

Wang, D. & Hui, L., 2007. Nonverbal language in cross culture communication. *Sino-US English Teaching,* Vol. 4(10), Serial No.46, USA.

Warkentin, M. E., Sayeed, L. & Hightower, R., 1997. Virtual teams versus face-to-face teams: An exploratory study of a web-based conference system. *Decision Science,* Vol. 28(4), pp. 975-996.

Weiss, H. M. & Cropanzano, R., 1996. Affective events theory: A theoretical discussion of the structure, causes and consequences of affective experiences at work. *Research in Organizational Behaviour,* Vol. 18, pp. 1-74.

Wen-Baw, L., 2007. The exploration of customer satisfaction model from comprehensive perspective. *Expert System with Application,* Vol. 33(1), pp. 110-121.

Wiener, M. & Mehrabian, A., 1968. Language within language: Immediacy, a channel in verbal communication. New York: Appleton-Century-Croft.

Williams, K.Y. & O'Reilly, C. A., 1998. Demography and diversity in organizations: A review of 40 years of research. *Research Organizational Behaviour,* Vol. 20, pp. 77-140.

Wilson, J. M., Straus, S. G. & McEvily, B., 2006. All in due time: The development of trust in computer- mediated and face-to-face teams. *Organizational Behaviour & Human Decision Processes,* Vol. 99(1), pp. 16–33.

Wing, E., 2009. Rivit Architecture 2010 no experience required. Indianapolis, Indiana, USA: Wiley Publishing, Inc.,

Wong, M., 2006. Emotion assessment in evaluation of affective interfaces, Msc. Dissertation, University of Waterloo, Canada

Wong, C. H., 2007. ICT implementation and evolution: Case studies of internet and collaborative environment in UK construction enterprises, *Construction Innovation: Information, Process, Management,* Vol. 7(3), pp. 254-273.

Xiaolong, X., Yaowu, W. & Qiping, S., 2007. The application of ICT in collaborative working in construction projects: A critical Review. In: Proceeding of International Conference on Convergence Information Technology, IEEE. Washington, 21-23 November, pp. 2266-2272.

Xiaolong, X., Qiping, S., Hongqin, F., Heng, L. & Shichao, F., 2012. IT supported collaborative work in A/EC projects: A ten-year review. *Automation in Construction,* Vol. 21, pp.1-9.

Yang, B., Garcia-Molina, H., 2002. Improving search in peer-to-peer networks. In: proceeding of the 22nd International Conference on Distributed Computing System. Washington, 2-5 July, USA, pp.5-14.

Yates, S. J., 2001. Gender, language and CMC for education. *Learning and Instruction,* Vol. 11(1), pp. 21-34.

Yuan, J., Liberman, M. & Cieri, C., 2006. To-ward an integrated understanding of speaking rate in conversation. In: Proceeding of the ICSLP Conference. Pittsburgh, 17-21 September, USA, pp. 541-544.

Zaneldin, E., Hegazy, T. & Grierson, D., 2001. Improving design coordination for building projects. II: A collaborative system. *ASCE,* Vol. 127(4), pp. 330-336.

Zurita, G., Baloian, N. & Baytelman, F., 2008. A collaborative face to face design support system based on sketching and gesturing. *Advanced Engineering Informatics,* Vol. 22(3), pp. 340-349.

Appendices

Appendix A

This appendix explains the bill of quantity for the model used in the experiments

No.	Details	Unit	Quantity	Price ($)	Amount ($)	Duration (day)	Backup amount ($)10% of the amount
	Civil engineering works						
1	Works of brick building with cement for exterior wall(thickness200mm)	M3	260	250	65000	30	6500
2	Works of brick building with cement for interior wall (thickness 90mm).	M3	225	200	45000	25	4500
3	Works of floor (Generic150mm-filled with Tiles) for first floor.	M2	340	150	51000	35	5100
4	Works of floor (Generic 300mm with ceramic) for second floor.	M2	340	175	59500	40	5950
5	Supplying fence door type: Timber–side hung(1):2(2271*2051)mm	M2	1	800	800	1	80
6	Supplying and installation door (M-double flash :1830mm*1981mm)	No	1	600	600	1	60
7	Supplying and installation interior doors (m-single flash: 915mm-2134mm).	No	12	300	3600	5	360
8	Supplying and installation windows (m-casement 3*3 with trim: 915mm*1220mm).	No	9	400	3600	3	360
9	Supplying and installation windows(m-combination Rtp with trim:915mm*1830mm)	No	9	400	3600	3	360
10	Work plaster with painting for interior wall and ceiling	M2	2200	50	110000	40	11000
11	Work covering to the exterior wall by brick.	M2	600	100	60000	30	6000
12	Works of the roof building by using warm-roof concrete.	M3	350	250	87500	45	8750
13	The implementation of stair (190mm max riser 250mm going, railing: 110mm) according to the drawing and model.	Lump sum	Lump sum	5000	5000	10	500
	Supplying and installation furniture and mechanical equipments works.						
14	M-Bed-Box double(1346mm-1880mm)	No	6	100	600	2	60
15	M-sofa:1830mm	No	8	100	800	2	80
16	M-Bench-Locar	No	6	100	600	2	20

	Room(1220mm*475mm*356mm)						
17	Television-Plasma 42"	No	6	350	2100	2	210
18	Fan coil unit(1200mm)	No	6	250	1500	2	150
19	Radiator-cast iron (900mm)	No	8	200	1600	2	160
20	M-boiler 535mm*910mm*810mm	No	2	500	1000	2	100
21	M-air conditioner-outside unit 720mm*720mm*950mm.	No	2	1500	3000	2	100
	Work of the site Architecture, fence, parking area and planting according to the drawing and model.	Lump sum	Lump sum	10000	10000	30	1000
	Electrical works						
22	Lump general	No	12	2	24	2	2.4
23	Outlet-communication: CCTV	No	8	20	160	3	16
24	Dbl socket-switched: double	No	14	5	70	3	7
25	Luminaire Dol:1200mm long	No	12	10	120	3	12
26	Push button: single	No	1	25	25	1	2.5
	Plumbing fixture works						
29	M-sink-Triple :1090*560mm	No	2	200	400	1	40
30	Bath with accessories	No	2	300	600	2	60
31	Shower head.	No	2	200	400	2	40
32	Sink-bathroom(4):660*560	No	4	100	400	2	40
33	M-toilet-pomes tic.	No	2	150	300	2	30
Tot					**518899**	**335**	**51650**

Appendix B

This appendix consists of two parts: Part1 concerns the FTF task used in the FTF meeting and Part2 relates to the CMC task used in the CMC meeting. The task items in CMC are pre-distributed between the two users, since the tasks involved access to specific Revit worksets, and these are pre-assigned between the two users. This pre-assignment is not done in FTF since there is only one computer and once copy of Revit, and both users use the same common access to all the worksets.

FTF Task

Method Type	User1 name	User2 name	Experiment number	Date of the experiment	Team number

1-Exterior Walls: The exterior wall used in this model is a basic generic-90 mm brick wall (brick 10cm).

A-Discuss how to change this wall to a basic with a generic 225 mm masonry double wall (Brick 48cm) or (Brick 36 cm). The discussion should include aspects such as strength, cost, resource availability, etc.

B- Discuss how to change this wall to a retaining-300 mm concrete wall (with 30 cm reinforced concrete) or (block covered with 36 cm brick). This discussion should also include aspects such as strength, cost, resource availability, etc.

Material	**Brick 48 cm**	**Brick 36 cm**	**Block 48 cm**	**Block covered with brick 36 cm**	**Reinforced concrete 30cm**
Price/M3	250$	200$	150$	250$	500$

C-Discuss how to decrease the number of windows on every side of the building from keeping energy view.

D-Discuss how to add a new exterior door to the building (with an M-double–flash1830*1930mm) facing in an easterly direction for emergency use.

E-Discuss to move the windows next to the old building to other locations in the same rooms in order to improve their lighting and ventilation functions.

2-Floor of the building: The floor used in this model is a 150mm floor (concrete).

A-Discuss how to change the floor to 200 mm beam and block (a tie beam with 20cm BRC concrete). Your discussion should include aspects such as strength, cost, resource availability, etc.

B- Discuss how to change the floor to a concrete-domestic 425 floor (with 42.5cm reinforced concrete 42.5cm). Include points such as strength, cost, resource availability, etc.

C-Discuss how to change the floor to a generic 150mm filled tile floor (this constitutes 15 cm concrete with tile). Include points such as strength, cost, resource availability, etc.

D-Discuss how to change the floor to a generic 300mm with ceramic floor (300 cm concrete with ceramic). Includes points such as the strength, cost, resource availability, etc.

E-Discuss how to change the floor to one with a standard wood finish (the wood measuring 20cm). You should cover aspects such as strength, cost, resource availability, etc.

Material	**Concrete 15cm**	**Tie Beam with BRC concrete 20cm**	**Reinforced concrete 42.5 cm**	**Concrete with tiles 15cm**	**Concrete with ceramic 300cm**	**Wood 20cm**
Price/M2	75$	150$	300$	150$	125$	200$

3-Roof of the building: The roof used in this model is a generic-125mm roof (with 12.5 cm reinforced concrete)

A-Discuss how to change the shape of the roof to a truss shape and considers the benefits of these kinds of roofs from an economical point of view and for future maintenance.

B-Discuss how to provide resistance to atmospheric actions in the current roof.

C-Discuss the type of finishing layer for this roof and find a more suitable material than that currently being used.

D-Discuss how to change the current roof to a basic roof i.e. warm timber roof.

E- Discuss the rain pipe system for the building to establish if the current one is adequate.

4-Electrical work: The electrical fixtures used in this model consist of different types, these being distributed according to actual need.

A-Discuss the location of all the Dbl Socket-Switches and consider if they are ideal in all the rooms or should be redistributed.

B-Discuss the location of the light points (the general lamps) to establish if they are adequate for providing full lighting.

C-Discuss how to change the location of the communication outlet (CATV) in the wall between the bathroom and kitchen in order to increase its efficiency and make it easier to use.

D-Discuss the alternatives to the Luminaire Dbl which is 1200mm long. Which one is more economical and which one is more readily available on the market.

E-Discuss in general if the electricity fixtures are adequate for this model.

CMC Task

Method Type	User1 name	User2 name	Experiment number	Date of the experiment	Team number

1-Interior walls: The walls used in the model are a basic generic-90 mm brick wall (brick 10cm).

A-User2 should ask User1 for permission to move the exterior door (an M-Double-Flush: 1830*1981mm) 1.24m in order to increase the dimensions of the kitchen.

B-User2 should ask User1 for permission to move the stair to one meter in the direction of room2 to increase the dimensions of room 4.

C-User2 must ask User1 for permission to move the M-Bed-Box 1346*1880mm in room 4 to the other side in order to change the position of the door since it is located in front of the kitchen door. It will also be necessary to change the direction of opening for all the doors and handles.

D- Discuss how to increase the thickness of the interior wall to 150 mm. Your discussion should cover points such as strength, cost, resource availability, etc.

E- There is too much space at the end of the corridor. It is therefore necessary to create a new space in order to utilise the wasted area. Discuss how this can be done.

2-*Furniture, mechanical equipment and plumbing fixture distribution:* The model shows all the components.

A- User1 should ask User2 for permission to change the position of the interior door for room1 so that it located in the opposite direction in order to increase the efficiency of the fan coil unit.

B- User2 should ask User1 for permission to change the position of the plumbing fixture: 2D path in the bathroom so that it runs in another direction to make one line for the hot water (for the sake of economy).

C. User1 should ask User2 for permission to change the interior door in room2 because it is directly in front of the bed. Alternatively, the bed and TV locations can be changed.

D-Consider a redistribution of all the components in the model to other more appropriate positions. These elements should have, a regular distribution, and be efficient in these locations.

E-User2 should ask User1 for permission to change the type of table inside the kitchen as well as its location and to move the sink in front of the kitchen window.

3-Architectural design and site: The model shows the architectural view and site plan for the project.

A-User1 should ask User2 for permission to change the direction and position of the car park and to increase its capacity.

B-User1 should ask User2 for permission to create a new exterior door opening in another direction in the fence in case of emergency.

C-Discuss the site and green plants as well as their methods of distribution potentially providing the model with walk-ways between the plants.

D-Discuss how to increase the number of plants behind the building since there is too much space. In addition, add a new swimming pool.

E-User1 should ask User2 for permission to increase the height of the fence to 2.5m instead of 1m in order to improve security.

4- Exterior walls and Stairs: The exterior wall used in this model is a generic 200 mm brick wall and the stair used in the model is 19mm max riser 250 mm going, railing: 1100 mm.

A- User2 should ask User1 for permission to increase the dimensions of the windows in the kitchen and to decrease the dimensions and number of windows in the WC and bathroom.

B-User1 should ask User2 to move the interior wall between the WC and room 4 in order to add a new window for lighting purposes.

C-User2 should ask User1 for permission to change the width of the stairs to 1.25 m.

D-User2 should ask user1 to place another window over the stair in order to increase the lighting inside the building.

E-Discuss the comforts of the stair for use by all age groups and see if its location in the middle of the building is suitable. You should also consider if there is a need for an extra stair.

*****Notice: User1 has the following two worksets

1-Furniture, mechanical equipment and plumbing fixture distribution.

2-Exterior walls and stairs.

User 2 has two has the following two worksets

1-Interior walls.   2- Architectural design and site.

Appendix C

This appendix gives a prototype of calculations which is used to analysis any experiment. It has many tables each one explains specified point in the analysis of the experiment results.

Experiment Analysis

Table 1: The details of analysis of an experiment

Time (minute)	5	10	15	20	25	30	35
Numbers of words said by team (User1& User2)	300	270	250	280	290	320	325
Number of work related words said by team (User1& User2)	275	250	228	262	280	305	295
Number of non-work related words said by team (User1& User2)	25	20	22	18	10	15	30
Number of words said by User1	180	150	150	160	160	180	175
Number of words said by User2	120	120	100	120	130	140	150
Number of work related words said by User1	165	138	138	150	150	170	155
Number of work related words said by User2	110	112	90	112	130	135	140
Number of non-work related said by User1	15	12	12	10	10	10	20
Number of non-work related said by User2	10	8	10	8	0	5	10
Number of words said emphatically by User1	15	10	15	20	10	12	12
Number of words said emphatically by User2	0	0	0	10	10	10	8
Number of words said softly by User1	0	0	0	0	0	0	0
Number of words said softly by User2	15	12	10	8	0	0	0
Number of pauses by User1	0	2	4	2	1	1	0
Number of pauses by User2	0	2	2	2	1	0	0
Time(sec) spent by User1 during the experiment	170	160	155	158	160	165	155
Time(sec) spent by User2 during the experiment	130	140	145	142	140	135	145
Working time(sec) spent by team (User1 & User2)	259	236	230	250	273	275	277
Working time(sec) spent by User1 during the experiment	148	125	120	130	145	151	144
Working time(sec) spent by User2 during the experiment	111	111	110	120	128	124	133
Wasted time spent by team (User1 & User2)	26	44	52	40	19	16	13

Non-specific time spent by team (User1 & User2)	15	20	18	10	8	9	10

Table 2: Number of exchanges between User1 and User2 (percentage of interaction)

Time	**5**	**10**	**15**	**20**	**25**	**30**	**35**
Number of exchanges	19	16	12	17	18	21	23

Number of exchanges=126

Table 3: Percentage of working, wasted and non-specific time in experiment

Time	**Amount(minutes)**	**percentage**
Working time	30.0	0.857
Wasted time	3.5	0.1
Non-specific time	1.50	0.043

Table 4: The details of productivity during the time intervals for experiment

Time intervals(minutes)	**Productivity in(points)**	**Cumulative productivity in(points)**
5	1.0	1.0
10	0.625	1.625
15	0	1.625
20	0.75	2.375
25	1.0	3.375
30	1.5	4.875
35	1.75	6.625

Table 5: The productivity for each user during the experiment

Time (minute)	5	10	15	20	25	30	35
Productivity by User1(points)	0.58	0.362	0	0.435	0.58	0.87	1.015
Productivity by User2(points)	0.42	0.263	0	0.315	0.42	0.63	0.735
Total productivity(points)	1.0	0.625	0	0.75	1.0	1.5	1.75

User1 %= 58%

User2 %= 42%

Table 6: The wasted time spent by each user in experiment

	Time (seconds)	5	10	15	20	25	30	35	Total
User 1	**Time for non work related words**	15	12	12	10	10	5	7	71
	Time for pauses	0	12	20	12	5	5	0	54
User 2	**Time for non work related words**	11	8	10	8	0	6	6	49
	Time for pauses	0	12	10	10	4	0	0	36
Total time		26	44	52	40	19	16	13	210

Appendix D

This appendix is divided into two parts: the first section considers how to evaluate the design quality of the team in FTF while the second part can be used to evaluate the team design quality in CMC.

FTF Task

Evaluation of the design quality by the team (User1 & User2) in the experiment

Method Type	User1 name	User2 name	Experiment number	Date of the experiment	Team number

1. A (**Fundamental requirements**)

Did the team select the best and most correct solutions to change and move the elements of the exterior walls in Workset1?

(Extremely correct) 6 → 1 (Not at all)

[ ]

1-B (**Usability requirements**)

Did the team select the best and most correct solutions to make the design more usable in the exterior walls in Workset1?

(Extremely correct) 4 → 1 (Not at all)

[ ]

2. A (**Fundamental requirements**)

Did the team select the best and most correct solutions to change and move the elements of the floor of the building in Workset2?

(Extremely correct) 6 → 1 (Not at all)

[ ]

2- B (**Usability requirements**)

Did the team select the best and most correct solutions to make the design more usable on the floor of the building in Workset2?

(Extremely correct) 4 → 1 (Not at all)

☐

3. A (**Fundamental requirements**)

Did the team select the best and most correct solutions to change and move the elements of the roof for the building in Workset 3?

(Extremely correct) 6 → 1 (Not at all)

☐

3-B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable in the roof of the building in Workset 3?

(Extremely correct) 4 → 1 (Not at all)

☐

4. **A** (**Fundamental requirements**).

Did the team select the best and more correct solutions to change and move the elements of electrical work in the Workset4?

(Extremely correct) 6 → 1 (Not at all)

☐

4. B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable in the electrical work of the building in Workset 4?

(Extremely correct) 4 → 1 (Not at all)

☐

CMC Task

Evaluation of the design quality by the team (User1 & User2) in the experiment

Method Type	User1 name	User2 name	Experiment number	Date of the experiment	Team number

1. A (**Fundamental requirements**).

Did the team select the best and most correct solutions to change and move the elements of the interior walls in Workset1?

(Extremely correct) 6 → 1 (Not at all)

1-B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable in the interior walls in Workset1?

(Extremely correct) 4 → 1 (Not at all)

2. A (**Fundamental requirements**).

Did the team select the best and most correct solutions to change and move the elements of the furniture and plumbing for the building in Workset2?

(Extremely correct) 6 → 1 (Not at all)

2- B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable with the furniture and plumbing of the building in Workset2?

(Extremely correct) 4 → 1 (Not at all)

3. A (**Fundamental requirements**)**.**

Did the team select the best and more correct solutions to change and move the elements of the architectural design and site for the building in Worksheet 3?

(Extremely correct) 6 → 1 (Not at all)

3-B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable in the architectural design and site of the building in Workset 3?

(Extremely correct) 4 → 1 (Not at all)

4. **A** (**Fundamental requirements**).

Did the team select the best and most correct solutions to change and move the exterior walls and stairs in Workset4?

(Extremely correct) 6 → 1 (Not at all)

4. B (**Usability requirements**).

Did the team select the best and most correct solutions to make the design more usable in the exterior walls and stairs of the building in Workset 4?

(Extremely correct) 4 → 1 (Not at all)

Appendix E

This appendix gives details to evaluate of behaviour profile for each user during an experiment in three categories of emotions positive, neutral and negative.

Method Type	User's number	User's name	Experiment number	Date of the experiment	Team number

	1 Very Low	2	3	4	5 Very high
A: Positive Emotions					
1 Was user ***cooperative***?					
2 Was user ***confident***?					
3 Did user take the ***leadership*** role frequently?					
4 Did user have strong ***emphasis*** in discussion?					
5 Was user ***committed*** to the work?					
6 Was user ***optimistic*** in the approach to the work?					
7 Was user ***respectful***?					
8 Was user ***patient***?					
B. Neutral Emotions					
9 Did user display ***cautiousness***?					
10 Did user show "***confused***"?					
11 Did user show ***worry***?					
12 Was user ***satisfied*** with selection of alternatives?					
13 Did user show ***surprise***?					
14 Did user show ***reluctance***?					
C. Negative Emotions					
15 Was user ***domineering***?					
16 Was user ***mocking*** of partner?					
17 Was user ***shy***?					
18 Was user ***aggressive***?					
19 Was user ***pessimistic***?					
20 Was user ***deceptive***?					
21 Did user play a ***clown***?					
22 Was user ***depressive***?					
23 Was user ***selfish*** regarding information?					
24 Did user seem ***disappointed***?					
25 Was user ***avoiding*** taking any action?					
26 Was user ***doubtful*** regarding information?					

Appendix F

This appendix shows the observation form for non-verbal communication which is used to records all user actions during the experiment.

Category	Movement	User1	User2
Emblems	Shake hand		
Illustrators	Staring at a particular object		
	Explicit eye contact with team members		
	Pointing at/out a particular object		
	Using hands to act out/illustrate a description		
	Moving in chair to new location		
	Hand movement to reinforce a description		
	Changing voice/tone to emphasise/enhance a point		
	Acting out/illustrating a description said by someone else (i.e. while as a listener)		
	Total		
Adaptor	Vertical head nod		
	Horizontal head shake		
	Resting cheek/chin on hand		
	Interlocking hands		
	Hand on head/forehead		
	Touching nose		
	Hand on thigh		
	Hand covering mouth		
	Changing body position on the chair		
	Crossing arms over the chest		
	Total		
Regulators	Holding up a hand (to interrupt/interject)		
	Hand waving (to signify refusal/rejection of what is being said)		
	A “thumb up” (to support/agree)		
	Using hand to stop other people speaking		
	Using hand to ask other people to wait		
	Waving index finger (to signify threatening)		
	Total		
Affect display	Smile or laughing		
	Looking around (puzzled, speechless, “a bit lost”)		
	Staring at ceiling		
	Total		