Factors Affecting Team Productivity in Face to Face and Computer Mediated Collaboration

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Abstract. Productivity is one of the main objectives in team working, and among other goals such as quality, efficiency, etc., it is a key to success in any organization. Team members have to work collaboratively and cohesively on the task, and the level of cooperation will also reflect on the final productivity. Many factors affect team productivity. Some are clear and obvious, e.g. technical and physical environmental factors, but other factors are more veiled, e.g. team behaviour and relationships. This paper examines how, and the extent to which, some of these factors affect the conceptual design of a building, in both Face to Face (FTF), and Computer Mediated Communication (CMC) collaboration. The productivity of a lone worker on the same conceptual design is also compared with the results achieved by a team.

1. Introduction

Previous researchers have evaluated productivity in Face-to-face (FTF) and Computer Mediated Collaboration (CMC). Hewage et al. (2008) claimed that CMC resulted in higher productivity than FTF. Bhappu & Crews (2005) noted that conflict between the team members is less in CMC and this makes for a good environment for decision making and increased productivity. Harpaz (2002) examined cost savings and productivity improvements in CMC. The current authors have also previous publications on comparing effectiveness of CMC and FTF (Hatem et al., 2012).

Four main factors affecting team productivity are now studied collectively, in a single FTF-CMC comparative study, and explicitly in relation to building concept design (i.e. an engineering task): team expertise, cultural differences, team emotions and prior relationship between team members. Previous researchers have studied some of these aspects, separately, and on non-engineering tasks. The current work is informed by, and integrates, these previous studies.

Barrick et al. (1998) showed that team emotion has great effect on the team, e.g. when team members were anxious or stressful, their behaviour tends to be more conflictual and less socially cohesive. Reagans et al. (2005) concluded individual expertise normally contributes positively to team expertise which then affects team productivity. Riordan & Kreuz (2010) concluded that CMC team members are less affected by emotional factors than FTF team members. Diversity in team culture also has potential effects on team productivity; a multicultural team can have advantages in producing new plans and ideas (Iles & Hayers, 1997). Huckman et al. (2009) revealed that team familiarity not only improves team performance, but it helps team members to overcome the difficulties related to weak collaboration or task complexity. Ramalingam & Mahalingam (2010) observed and described prototypes between the interactions of project network participants and identified certain enabling conditions such as team fraternisation and richness in communication that impacted process performance and then increase team production.

2. Methodology

A series of experiments was conducted involving two users in both FTF and in CMC (see Figs.1 and 2) respectively undertaking tasks relating to an existing Revit Architecture 3D computer model of a building. The users were required to carry out "problem-solving" tasks which all related to required improvements of the building model which contained some deliberate initial flaws and inadequacies. The Revit model came in subdivided worksets (i.e. a specified subset of the model, e.g. the "Exterior wall" workset would contain walls, windows and doors) so that collaboration and sharing across worksets were necessary to complete the task. All the users were initially trained in Revit.

Figure 1: an FTF experiment

Figure 2: a CMC experiment

The required improvements and corrections were distributed across different worksets and productivity in this context was defined as the level of completion of the individual tasks. In total, there were twenty separate tasks, each carrying a score of 0.5, and hence 100% productivity equated to 10 points.

At the start of each task, the users were given written instructions on the individual tasks to be performed. The tasks were complementary but different for each of the two users within a team. The instructions were carefully devised so that the tasks could not be carried out without assistance from the other user. This approach enforced the need for collaboration and hence communication. Great care was taken before the experiments to ensure that each pair was given identical verbal and written instructions, and that the users were ignorant of 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 participants.

The system in this research had a central Revit file on a server computer which was accessed by the team. In the case of CMC, the two team members "owned" separate worksets so that the completion of a task required the team members to communicate, cooperate, collaborate, and "release" worksets to each other. An administrator monitored the collaboration process during the experiment through CCTV and also had master-access to the central file to see all the changes made by the users after the end of an experiment.

It has been found useful to classify the participants into teams according to their levels of expertise (see Table 1). Twenty teams were formed with four teams for each category of expertise, and each team produced results in both CMC and FTF, thereby giving an even and large spread of data across the range of experience. The same teams were also categorised

according to whether the members i) were from the same cultural background, and ii) had prior knowledge of each other, and the results were then accordingly examined.

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 (Kopelman et al., 2006; Mellers et al., 1999). These include symptoms such as postures, gestures, eye contact and facial expressions. The methodology adopted in this work for evaluating "emotions" is one widely used and originates from Ekman (1993) and so these emotions are placed into one of three categories: positive, neutral and negative emotions. Each user behaviour is assessed using a form (Appendix A, which is derived from Ekman, 1993) which elicits the appropriate emotion type, thus leading to a behaviour profile for each user.

Table 1: Type of team expert according to level of expertise

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

3. Factors Affecting Team Productivity

The impact of several factors influencing team productivity has been examined.

3.1 Emotional Profile

The impact and correlation of each category of user emotion on productivity is separately examined.

3.1.1 Total Positive Emotion

Figure 3 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 of 0.88 and 0.87 for FTF and CMC respectively (note: Spearman's Rank Correlation Factor has been used throughout). Equally, the slopes of best-fit straight line for FTF and CMC are very similar, which shows that positive emotional response is good for team productivity whether in FTF or in CMC, i.e. independent of the method of communication. However, it should also be noted early on that productivity does not solely depend on one factor and hence the other factors below also need to be taken into account.

Figure 3 shows that the productivity score for Expert-Expert are less affected by total positive emotions than in the other teams. For Expert-Experts, total positive emotions can increase but team productivity remains largely the same, for both types of communication. On the

other hand, there is a clear relationship between positive emotions with team productivity in the other expertise types, as shown by the broken best fit lines (in Fig. 3) which exclude data for Expert-Expert. Indeed, it is possible to see that the lower expertise groups (e.g. Novice-novice) have the largest spread of positive emotions, and productivity is more strongly dependent on positive emotions for these groups, although other factors such as the difference in the level of team expertise, cultural differences, etc. also have their contributions. It is significant to note that positive emotions observed was higher in CMC than in FTF for 75% of the experiments, but the reverse is true for 20%, and in the remaining 5%, positive emotions were equally displayed in FTF and CMC. This is not intuitive since it could be expected that the unfamiliar CMC environment, together with the additional overhead in a more laboured form of communication, would typically result in less positive emotions.

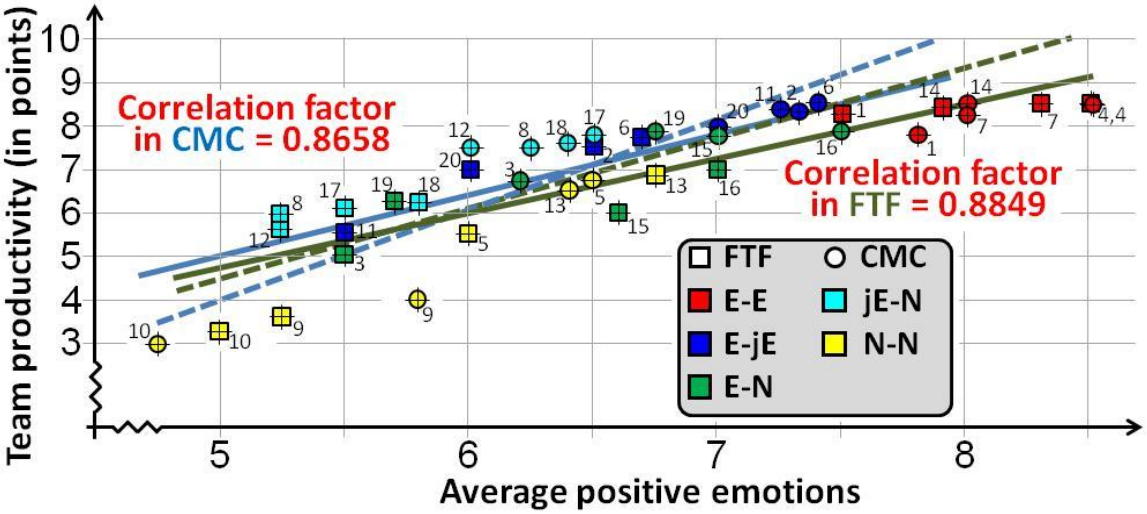

Figure 3: Total positive emotions of team and team productivity in FTF and CMC

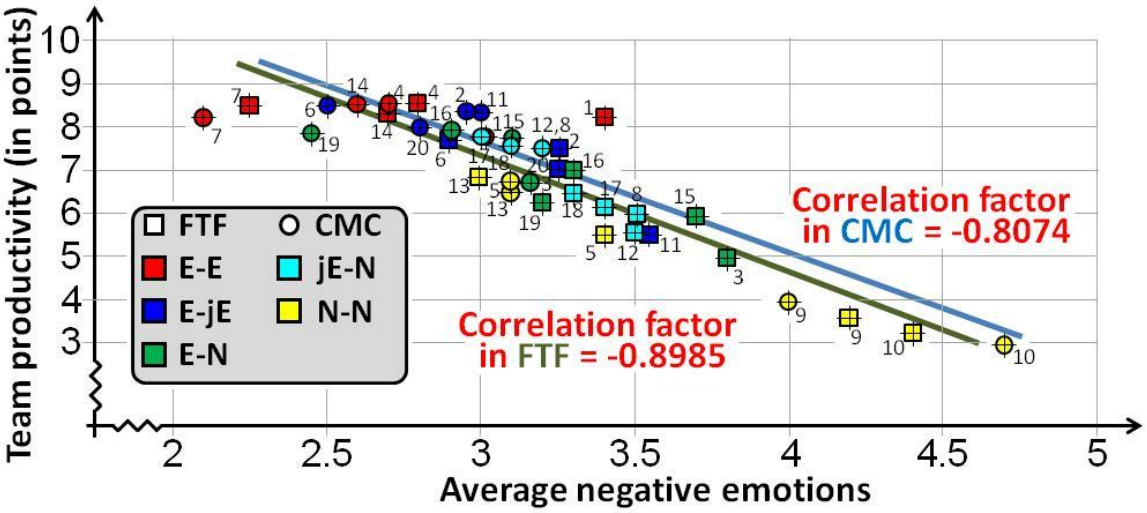

Figure 4: Total negative emotions of team and team productivity in FTF and CMC

3.1.2 Total Negative Emotion

Similar to the effect of positive emotions, there is a strong negative relationship between team productivity and the total amount of negative emotions. The negative emotions for each team were calculated as the aggregate of the negative emotions (i.e. by adding the score of negative emotions for User1 to User2). Figure 4 shows strong negative correlation between the total amount of negative emotions and team productivity, with FTF (-0.8985) slightly stronger than for CMC (-0.8074), and the slope of the best-fit straight line is marginally larger for FTF than for 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. 4, around -2.6) is double the size of the positive slope (Fig. 3, around +1.25).

Again, while the spread in the total negative emotions is considerable for the Expert-Expert teams, values of their team productivity stay similar, showing that the effect of the total negative emotions is negligible for these teams. Conversely, in other categories, and especially for Novice-Novice, the spread of negative emotions is also large but the productivity also varies. There is thus a definite link between the total negative emotions and team productivity. The total negative emotions score was higher in CMC than in FTF, for 85% of the total experiments (with the reverse to be true for the remaining 15%). Together with the complementary conclusion in Section 3.1.1, we can say users in CMC exhibit a better emotional profile than FTF.

3.1.3 Total Neutral Emotion

Figure 5 shows the relationship between the total neutral emotions and team productivity for FTF and CMC. The total neutral emotion for each team has been aggregated in the same way as the total of positive and negative emotions. Here, it can be seen that there is no 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 that there is large spread with high productivity in the Expert-Expert teams and the productivity remains the same in spite of the very big spread in neutral emotions; while this is true to a lesser extent to all the other team types.

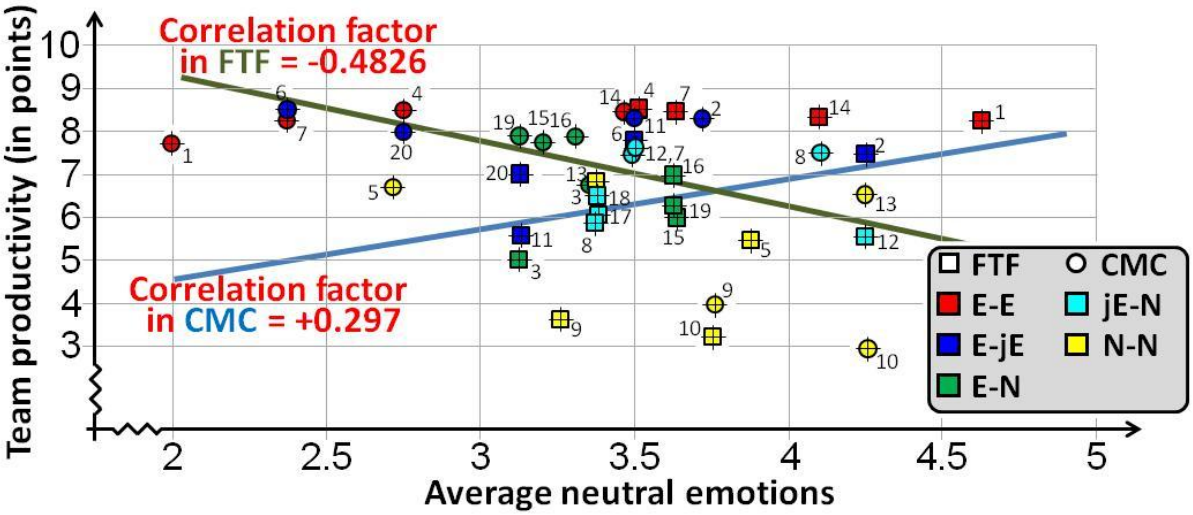

Figure 5: Total neutral emotions of team and team productivity in FTF and CMC

Since neutral emotions have no impact on team productivity, it was therefore deemed useful to concentrate further study on only positive and negative emotions. Since their effect on productivity has been noted as polarised, it has been found to be useful to combine positive and negative emotions scores into one quantity, namely, the differences between them. It is thus this combined quantity that is taken forward to examine productivity together with other factors such as team expertise, cultural differences and prior relationships.

3.2 Expertise Level

The level of expertise for any team is one of the most important factors affecting team productivity, both in FTF and CMC. In this paper, the users have been classified into expertise levels (see Table 1) which have been calculated as a summation of the two users' expertise for each team. Figure 6 shows the relationship between the expertise levels of the teams and their productivity. Additionally, through a coded key, Fig. 6 also shows all the team details, i.e. team number, whether team members have the same cultural background, whether they already knew each other before the experiment, and also the differences between the positive and negative emotion for a team.

It is evident from Fig. 6 that, productivity is most strongly related to the team expertise, and the other factors also in Fig. 6 seem to have less effect. The general trend shows the team type Expert-Expert (in red) have the highest productivity consistently, and team type Novice-Novice (in yellow) have the lowest productivity and with greatest variability, with the other team types located between them. It is clear that, except for the Expert-Experts, even within the same expertise level; there are differences in team productivity, which would thus be due to factors other than expertise level.

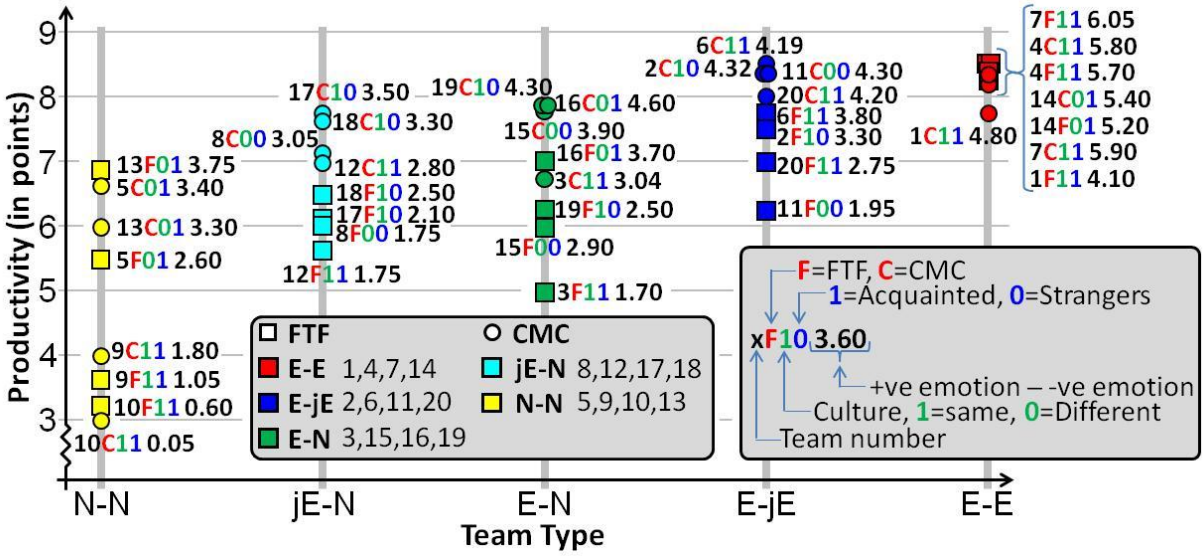

Figure 6: Team productivity and team type in FTF and CMC

However, it is true that, even within a single team type, there is still variation in the total number of years, and the type, of construction design experience. For example, in the Expert-Novice team type, the 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 so much of a spread of experience). 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.

3.3 Cultural Differences and Prior Relationship

The experiments have involved users who have come from a variety of cultures. Furthermore, some of the users knew each other before the experiment while others met in the experiment as strangers. According to the results in Fig. 6, it is apparent that culture differences and prior relationship have only a limited effect on team productivity, when compared to other factors such as the level of expertise or differences in emotional profiles.

A good example is found among the Expert-Expert teams (all have the same expertise level, all the team users knew each other beforehand), where Team 14 is the only team with members from different cultures. However, there is no notable difference in the productivity of Team 14, in both CMC and FTF, when compared to the other productivity values from the 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 showed near identical emotional difference score in CMC (4.19 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.

It is also clear prior relationship has not had much of an 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. 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. 6 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.

3.4 Differences between Positive and Negative Emotions

The measure of positive and negative emotions have been combined together into a single value (their difference) and used in the plot in Fig. 6. A study of the distribution of this differential value with productivity shows that, typically, with all things being equal, a big difference between positive and negative emotions is accompanied by a high productivity.

For example, for team type Expert-Expert, both Teams 1 and 4 have the same expertise level, same culture and prior acquaintance, but Team 4 has 20% more in the emotion difference, and 8% more in productivity (in CMC). The same pattern is observed for Teams 1 and 7 (in CMC) where Team 7 has 23% more emotion difference, and again 8% more productivity. The main difference in these groups is the emotion displayed during the experiments.

The same conclusion can also be arrived at by taking a more sweeping view of the distribution of difference in emotions in each expertise type, without drawing attention to whether the team members are from the same culture, or if they knew each other before hand, or whether the experiment was in CMC or FTF. Such a "broadbrush" scan of the data shows that within each team type, the high productivity experiments are also experiments where the teams displayed the highest difference between positive and negative emotions. As the difference decreases, there is also a corresponding decrease in productivity. Although there are two or three exceptions to the rule where a lower difference experiment has managed a higher productivity than a neighbouring data point, yet, the overall pattern is unambiguous and universally clear.

It can be concluded that within the same expertise level, the most influential factor affecting team productivity is the difference between the positive and negative emotions, i.e. how high are the scores for positive emotions alongside how low are the scores for negative emotions.

4. Comparison between Individual Productivity and Team Productivity

A further set of identical experiments involving single users working alone undertaking the same engineering design task was conducted. The differences in team productivity and the productivity achieved by an "equivalent" single user is now examined. 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 Junior experts and 3 Novices). Obviously, in these experiments, only one person was required to use the computer, and the documentation provided was the same as that used in the team FTF experiments. The user was given the same time, 35 minutes, to finish the task. The average productivity for each type of user is shown in Table 2.

Table 2: Average of individual productivity for single users according to their level of expertise

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

Figure 7 shows the relationship between the average productivity on the vertical axis for both teams and single users on the horizontal axis. The horizontal axis consists of two axes where the single user values have been scaled and superimposed on the team expertise such that a single expert is mapped onto the Expert-Expert team, a single novice is mapped onto the Novice-novice team, and the Junior-expert is deemed equivalent to the "average" in the Expert-Novice team. Although such a mapping is arguably only approximate, it is yet the best approximation that could apply to achieve comparison.

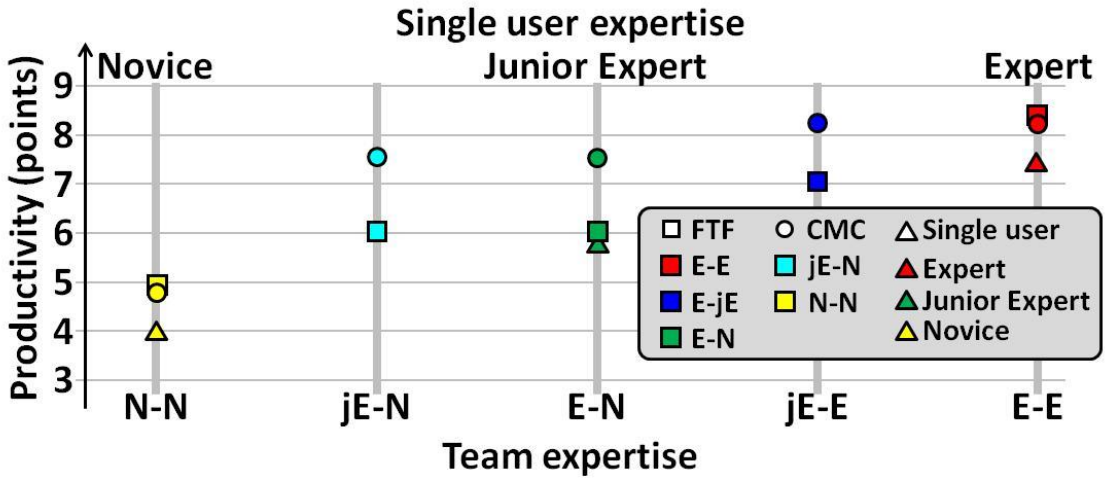

Figure 7: Average productivity for team and single user expertise

Figure 7 shows 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 in Fig. 7 even though it is actually built up from superimposing two different horizontal axes. This firstly provides support for validity of the way Fig. 7 is composed. However, it can also be noted in Fig. 7 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 time-limited tasks. Table 3 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 is 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 3: 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*	*1.5*	*22.56*	*26.75*
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*	*2.5*	*1.0*	*2.0*	*31.5*	*30.5*

Table 4: 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 4 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 has 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, 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. The lone user asked comparatively more questions, some of which were technical questions related to the Revit Architecture software (which were generally answered), while others were related to the task itself (which were not answered). 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. Conclusions

Although it should be noted that the number of experiments is small, and thus caution is needed to draw conclusions too widely, nonetheless there is good indication of some trends.

1. Many factors affect team productivity, but the most influential is the level of expertise. The second most important factor is the impact of the emotions. The emotions have been divided into three categories: positive emotion strongly and positively correlated with productivity, while negative emotion was negatively correlated with productivity. Neutral emotions, however, had little relationship with team productivity. Meanwhile, the cultural differences and prior relationships between users had some effect on team productivity, but difficult to know if this effect increased the productivity, or decreased it, at this stage.
2. Productivity is more strongly dependent on team/worker expertise than on method of communication, although productivity in CMC was generally better than in FTF.
3. Team productivity is higher than productivity from an equivalent single worker doing the same task. This is not entirely to be expected since the lone worker had the same resource level, except for a collaborative partner. It was further found that productivity is highly dependent on actual time spent working, which is highly correlated with degree of collaboration, leading to possibly why team productivity is higher.

6. References

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Appendix A: Scoring Sheet used to determine emotion profile

A: Positive Emotions	1 V Low	2	3	4	5 V High
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 ***confusion***?					
11 Did user show signs of being ***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 Did user ***avoid*** taking any action?					
26 Was user ***doubtful*** regarding information?					