Chapter 5
Pilot Study of Statistical and Entropic Description of Linkographs

This chapter presents a pilot study, using the ideas in Chap. 3, to examine two design sessions under two conditions; one being face-to-face and the other using computer mediation to simulate distant collaboration. Preliminary results are presented concerning clustering and entropic measures of the linkograph.

5.1 Two Sessions

This section presents the two cases used in a pilot study, together with the study's qualitative analysis. This data was collected for a larger study concerning team collaboration in a high bandwidth environment (CRC Construction Innovation project, titled: Team Collaboration in High Bandwidth Virtual Environments). Both sessions involved two designers collaborating on an architectural project. In this pilot, only the first sheet of each drawing is studied and compared.

5.1.1 In Situ Face-to-Face Design Session

The first case was an in situ design session carried out in a Sydney architects' office. Two architects, one more senior than the other, were involved in the design of a commercial building in Canberra's city centre. This design session occurred after a review and planning session, subsequent to a client meeting. In this session the designers revisited the relationship between vertical circulation and the void areas, in order to satisfy the client's preferences. The raw data was a video recording of the session. Figure 5.1 is one image from this session and Fig. 5.2 is the first sheet of the drawing that they produced in this session, which will be analysed.

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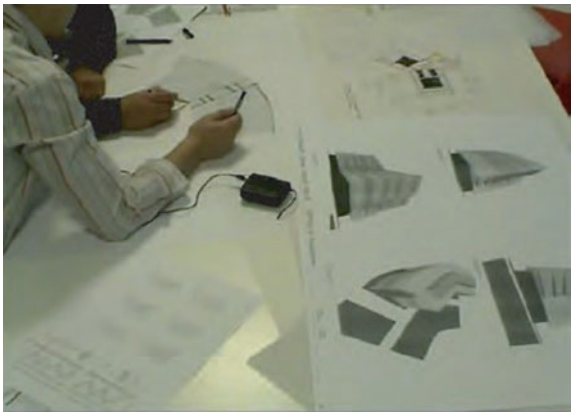

Fig. 5.1 Face-to-face session; Senior Architect starts drawing the core and the bridges after 4 min

In this session the architects were refining the design after the client's feedback. They needed to add a meeting place on the lobby level; also they needed to work on resolving related issues. The Senior Architect tried to incorporate the client's preferences and requirements, for example, very early in the protocol he mentioned "He wants an atrium", "I mean I know what he wants,", and "… I think he loves the idea of the verge…". During the first 10.5 min of the session, the designers frequently used drawing and gesturing to communicate without explicit verbalising, and nearly all verbalisations were accompanied by non-verbal actions; they referred to materials from previous designs; they drew different types of diagrams; sometimes separately; and they referred back and forth to the main plan drawing. Design actions were occurring in parallel, sometimes when the Senior Architect was working on the large drawing the Architect would draw on another sheet of paper or retrieve older drawings. There were interruptions, such as a phone call for about a minute towards the end. The leadership role was clear; the Senior Architect controlled and led the session. The session started with the Architect suggesting a few possible solutions related to the previous session, but the Senior Architect insisted on not jumping to a conclusion and started revisiting the issues and the client's preference by drawing a small plan at the bottom of the sheet (Fig. 5.2). He then

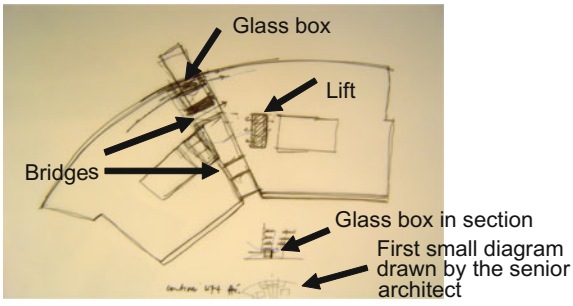

Fig. 5.2 The first sheet of the drawing the architects produced in the first 10.5 min, with annotations added

traced over the position of the bridges, which he regarded as important. Then they discussed the relationship among the lift, void, bridges and lobby. After about 6 min the Senior Architect discovered another problem with the setback of columns. They explored the position of the glass box and its relationship with other levels by drawing a small section with the setback of columns. The designers were dealing more with the structural or formal aspects of the design in this session—where things should be and how they related to each other, in order to satisfy the client. This sheet, Fig. 5.2, was mostly drawn by the Senior Architect; the other Architect drew a small diagram on another sheet.

5.1.2 *In Vitro NetMeeting Design Session*

The second case was an in vitro session which simulated the distance collaboration of two designers, an Architect and a Landscaper, with the use of computer-mediated tools. Tangible interfaces, Smartboard and Mimio (Smartboard and Mimio are brands of touch-screen interfaces that use different mechanisms. Smartboard is the wall-mounted touch-screen display in Fig. 5.3 and Mimio is attached to a rear-projected horizontal frosted glass table surface), together with Microsoft NetMeeting were used in this experiment. NetMeeting contains a shared whiteboard and a video conferencing tool. A more detailed experimental setup is included in

Fig. 5.3 NetMeeting session; the designers translating the issues into drawing at the beginning of the session

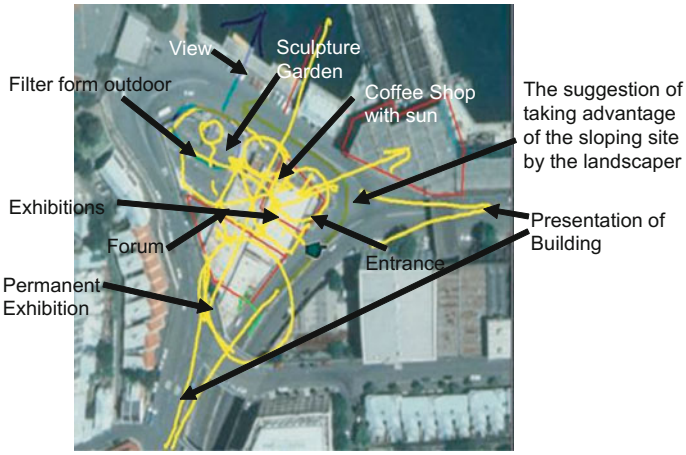

Fig. 5.4 The first sheet of the NetMeeting session, mostly drawn by the Architect

Appendix C. The designers were asked to design an art gallery in a harbour-front triangular site with level changes; the design brief and related materials are attached in Appendix B. Both their displays and actions were recorded as shown in Fig. 5.3. Figure 5.4 is the first sheet that they produced, which will be studied and compared in this pilot study; annotations are added to show the meaning of the drawing.

In this session the designers were given a new design task, so they were focusing more on the functional or conceptual aspect of the design, with time spent on studying the brief. The Architect started the session by trying to figure out the scale of the site in relationship to the brief. He complained that there was nothing there to scale with, and he could only do a mockup. The Landscaper proposed to work out only the appropriate relationship of functional spaces and their approximate sizes. The Architect then started reading the brief aloud with his added interpretation. Following that, the Architect clarified with his partner whether she could see his pointer and started drawing, proposing the main exhibition area on the south side of the site. The Landscaper noticed that there was a level change in the site and suggested taking advantage of that. Reacting to the suggestion, the Architect proposed the location of the central courtyard, entrance and connectivity. Then within the last 1.5 min the Architect produced the remainder of the design in the first sheet with the contribution of the Landscaper, which included the exhibition areas, the coffee shop with northern sun, the sculpture garden with a view, and the forum. Figure 5.4 is the capture of the first page from the screen and the annotations were added by consulting the verbal protocol. Overall we can observe that the Architect took the leadership role in this session and did most of the drawing.

5.1.3 *Qualitative Differences of the Two Sessions*

The design tasks between the two sessions were very different. In the face- to-face session it was a very specific re-design of the circulation space to satisfy the client's requirements for a commercial building. In the NetMeeting session it was about developing a block model preliminary scheme for a proposed art/craft gallery. In the NetMeeting session, they did not have the baggage of previous decisions, whereas in the face-to-face session they had to consider the impact of every move they made on the overall form and structure. For example, they could not just add the requested meeting space to the design without considering the location of the lift.

Although in both sessions the leadership roles were clear, the leadership styles were different. In the face-to-face session, the Senior Architect asserted his leadership by rejecting or correcting ideas suggested by the Architect. For example, after the Architect suggested the location, the Senior Architect responded, "We can't afford the area". In the NetMeeting session the Architect affirmed the Landscaper's idea and developed it further. Some examples of the affirmation are: "that would be gorgeous" and "correct," cause then you…".

The communication in the face-to-face session depended a lot on the use of gestures and tacit knowledge. "… remember we had a central thing here to here (gesturing locations using pen)" is an example from the protocol that contains both tactic knowledge of "a central thing" and gestures of location. In the NetMeeting session, neither assumed the other party had read her/his gesture. The Architect specifically asked "so can you see my mouse? my pointer?" Also, in the NetMeeting session interactions were more sequential and consisted of more affirmations and there was no interaction among gestures. There were more interactions among ideas, drawings, gestures and verbal communications in the face-to-face session.

5.2 Linkography Analysis of Cases

In the face-to-face session, the architects used 10.5 min to finish the first sheet of drawing. Ninety-eight moves were segmented and 299 links were constructed. Of these 98 moves, the architect contributed 38 moves and the Senior Architect contributed 60 moves. In the NetMeeting sessions the Architect and Landscaper took 6.5 min to produce the first sheet, with 97 moves and 277 links. The Landscaper contributed 37 moves and the Architect contributed 60 moves. Figures 5.5 and 5.6 show the linkographs of the two sessions. At the time these linkographs were generated by using a program written in AutoLisp (AutoLisp is a scripting environment within AutoCad). Now there is a publicly available software package to produce the linkograph of an FBS-coded protocol (LINKODER 2011). The critical

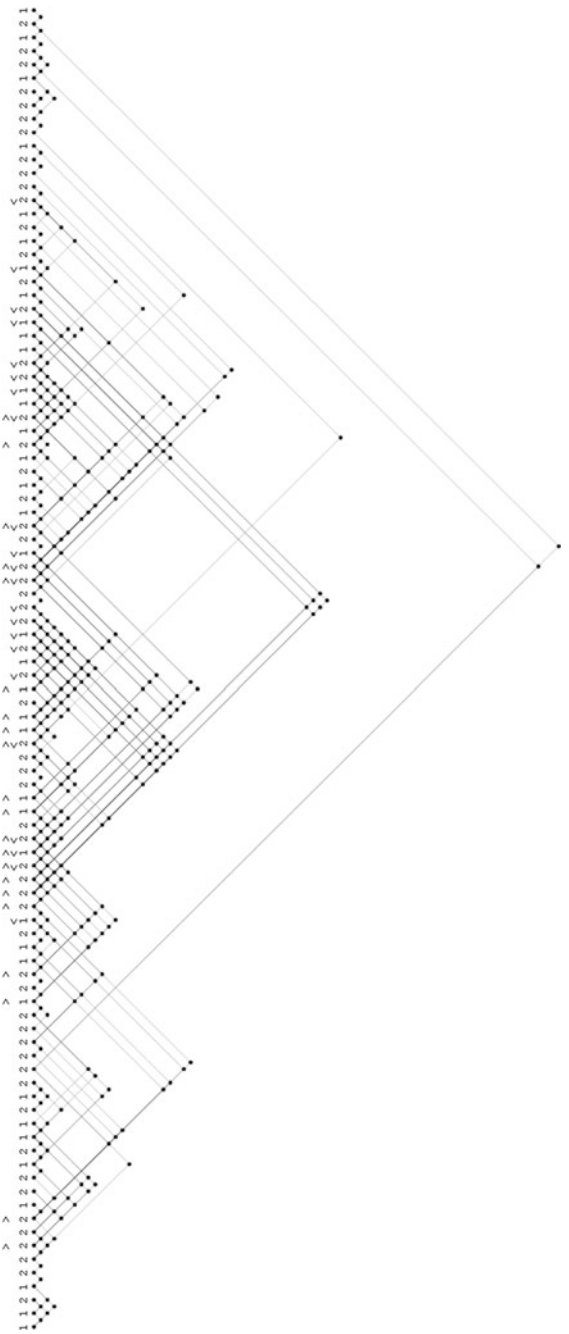

Fig. 5.5 The linkograph of the first 10.5 min of the face-to-face session, with "1" representing the Architect and "2" representing the Senior Architect

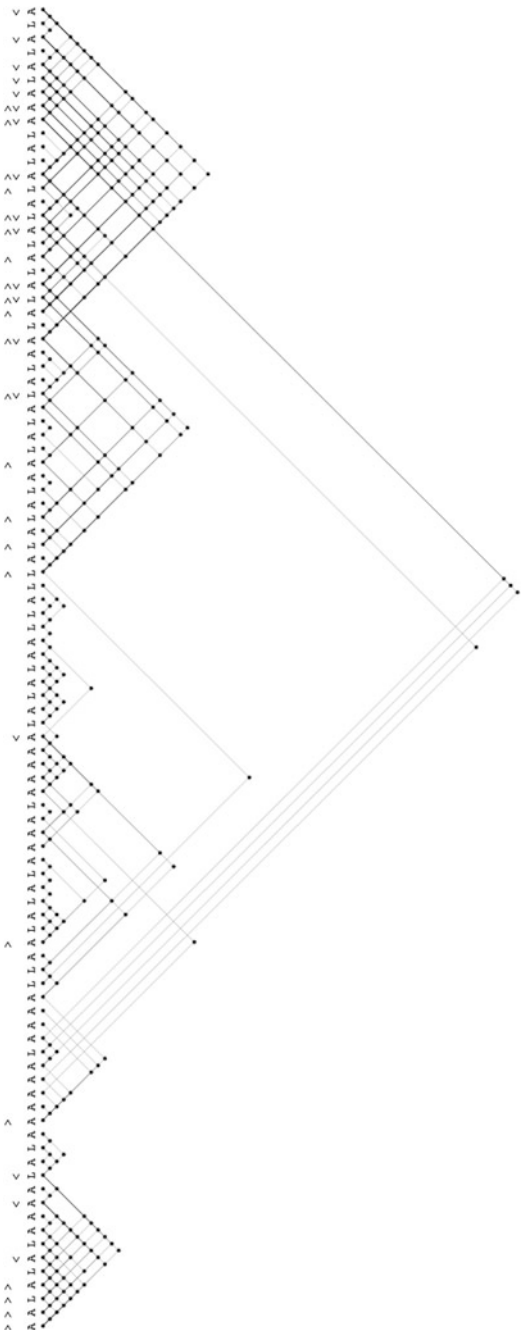

Fig. 5.6 The linkograph of the first 6.5 min of the NetMeeting session, with "A" representing the Architect and "L" representing the Landscaper

Table 5.1 Critical moves with more than 5, 6, and 7 links of the face-to-face session

	CM^5 (% CM^5)	CM^6 (% CM^6)	CM^7 (% CM^7)
Forelinks	21 (21.4)	17 (17.3)	13 (13.3)
Backlinks	22 (22.4)	15 (15.3)	7 (7.1)
Total	43 (43.9)	32 (32.7)	20 (20.4)

Table 5.2 Critical moves by individuals in the face-to-face session, with A and SA representing the Architect and Senior Architect respectively

	CM^5		CM^6		CM^7	
	A (%)	SA (%)	A (%)	SA (%)	A (%)	SA (%)
Forelinks	7 (18.5)	14 (23.3)	6 (15.8)	11 (18.3)	4 (10.5)	9 (15.0)
Backlinks	7 (18.5)	15 (25.0)	5 (13.2)	10 (16.7)	1 (2.6)	7 (11.7)
Total	14 (36.8)	29 (48.3)	11 (28.9)	21 (35.0)	5 (13.2)	16 (26.7)

The values inside the brackets show the critical move percentages of total moves

moves with more than five links (CM^5) are indicated by: ">" for forelinks and "<" for backlinks. In the face-to-face session, links were dense over the whole session, whereas in the NetMeeting session links were dense towards the end of the session. There was an obvious chunk at the beginning of the NetMeeting session, but not in the face-to-face session.

The link indexes of the face-to-face and the NetMeeting sessions are 3.05 and 2.88 respectively. Tables 5.1 and 5.3 record the critical moves and their percentages over the total number of moves (% CM) of the face-to-face session and the NetMeeting session respectively. The face-to-face session has a total of 43.9 percent of critical moves with more than five links (% CM^5) which is a marginally higher than the NetMeeting session which has a total of 41.2 % CM^5. From these values, the face-to-face session seems to have been more productive than the NetMeeting session. However, the NetMeeting session has a higher % CM^7 than the face-to-face session, 28.9 against 20.4. Tables 5.2 and 5.4 show the breakdown of critical moves by individuals of the two sessions; the critical move percentages of the total number of moves are in brackets. These correspond well with the analysis of the leadership role, with the leaders possessing not only more moves but also higher % CM.

Table 5.3 Critical moves with more than 5, 6, and 7 links of the NetMeeting session

	CM^5 (% CM^5)	CM^6 (% CM^6)	CM^7 (% CM^7)
Forelinks	22 (22.7)	17 (17.5)	14 (14.4)
Backlinks	18 (18.6)	16 (16.5)	14 (14.4)
Total	40 (41.2)	33 (34.0)	28 (28.9)

Table 5.4 Critical moves by individuals in the NetMeeting session, with L and A representing the Landscaper and Architect respectively

	CM^5		CM^6		CM^7	
	L (%)	A (%)	L (%)	A (%)	L (%)	A (%)
Forelinks	8 (21.6)	14 (23.3)	6 (16.2)	11 (18.3)	5 (13.5)	9 (15.0)
Backlinks	5 (13.4)	13 (21.7)	4 (10.8)	12 (20.0)	4 (10.8)	10 (16.7)
Total	13 (35.1)	27 (45.0)	10 (27.0)	23 (38.3)	9 (24.3)	19 (31.7)

The values inside the brackets show the critical move percentages of total moves

5.3 Statistics and Clustering of Links

This section uses the statistical methods described in Chap. 3, Sect. 3.2 to analyse the two sessions.

5.3.1 Statistical Description of the Two Sessions

Tables 5.5 and 5.6 present the statistical descriptions of the linkographs, in reference to the position of links, for the face-to-face and NetMeeting session respectively. Figures 5.7 and 5.8 are the corresponding scatter plots.

The NetMeeting session has a higher X mean and a higher standard deviation than the face-to-face session. This indicates, in general, that the links in the NetMeeting session are distributed more towards the end of the session compared to the face-to-face session. This corresponds to the qualitative analysis of the NetMeeting session, where numerous interrelated actions occurred in the last 1.5 min. The NetMeeting session also has a higher standard deviation, indicating that the nodes are more dispersed than in the face-to-face session. This also matches the qualitative understanding, because at the beginning of the NetMeeting session the designers were trying to figure out how to scale in the shared whiteboard, which formed a separate chunk at the beginning, whereas in the face-to-face session we do not observe this kind of separated chunk. The face-to-face session has a higher mean value of Y suggesting that the face-to-face session has links that are further apart, that is, longer links than in the NetMeeting session. Also, the face-to-face

Table 5.5 Descriptive statistics of the face-to-face session with 299 links

	Minimum	Maximum	Mean	Std. deviation
X location	1.50	97.50	48.23	21.81
Y location	0.50	38.50	3.97	5.10

Table 5.6 Descriptive statistics of the NetMeeting session with 279 links

	Minimum	Maximum	Mean	Std. deviation
X location	1.50	96.50	57.83	29.85
Y location	0.5	34.50	3.60	4.61

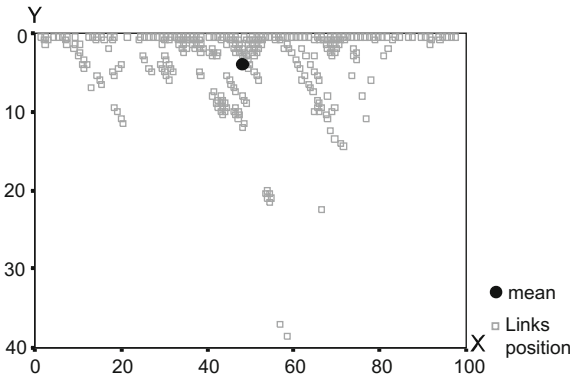

Fig. 5.7 Scatter plot of the face-to-face session

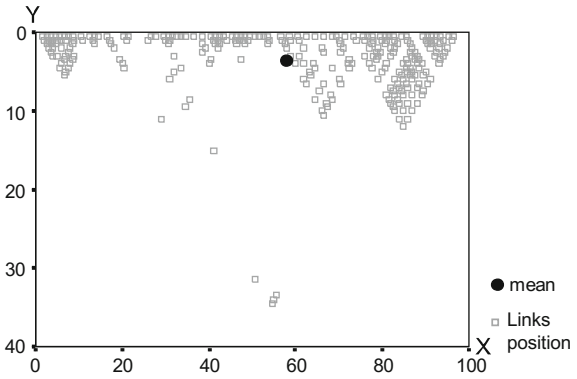

Fig. 5.8 Scatter plot of the NetMeeting session

session has a higher standard deviation, which suggests a greater mixture of long and short links. This agrees with the qualitative analysis, since in the face-to-face session, the designers referred to and traced over their drawing often, causing these long links.

5.3.2 *Cluster Analysis of the Two Sessions*

Tables 5.7 and 5.8 show the results from the cluster analysis (using SPSS) of the face-to-face and the NetMeeeting sessions respectively; Figs. 5.9 and 5.10 represent their corresponding scatter plots.

Results of the Face-to-Face Session

Figure 5.11 illustrates the variations within clusters and the number of links within each cluster. It shows that the four clusters are well separated, with 95 % confidence that there is no overlapping (in the X direction). It also shows that Cluster 4 is

Table 5.7 Centroids of the face-to-face session

Cluster	X		Y	
	Mean	Std. deviation	Mean	Std. deviation
1	14.18	6.97	2.82	2.95
2	42.50	7.42	3.56	3.29
3	71.67	10.11	3.27	3.72
4	56.39	4.12	24.72	7.43
Combined	48.23	21.81	3.97	5.10

Table 5.8 Centroids of the NetMeeting session

Cluster	X		Y	
	Mean	Std. deviation	Mean	Std. deviation
1	9.04	5.77	1.87	1.43
2	39.40	7.38	2.12	2.97
3	85.61	5.06	4.09	3.00
4	65.13	5.65	3.51	2.98
5	53.88	2.29	33.38	1.31
Combined	57.83	29.85	3.60	4.61

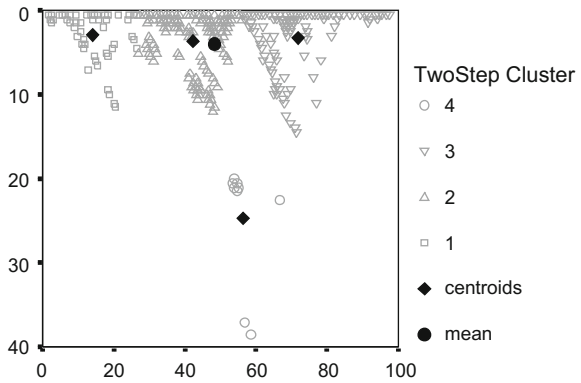

Fig. 5.9 Scatter plot of the clusters of the face-to-face session

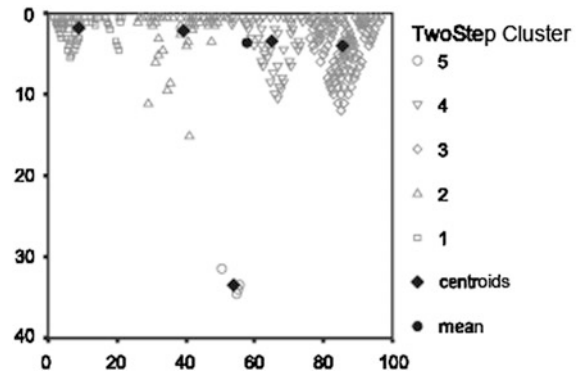

Fig. 5.10 Scatter plot of the clusters of the NetMeeting session

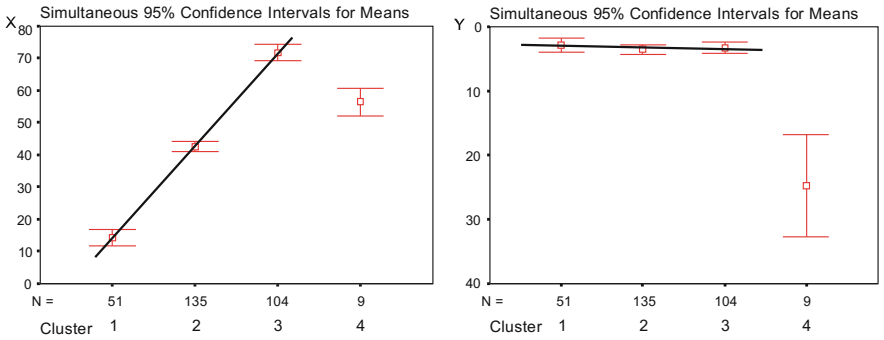

Fig. 5.11 Within cluster variation for the face-to-face session

different from the others. Cluster 4 seems to be the outlier in statistical terms; it contains only nine links. Neglecting this cluster for this moment, Clusters 1, 2 and 3 map well with the qualitative analysis. In Cluster 1, with 51 links, the two designers were discussing issues arising from the previous meeting. In Cluster 2, the biggest cluster, with 135 links, the Senior Architect started drawing and they were considering the behavioural impact of moving the lift, void and bridge. In Cluster 3, with 104 links, the Senior Architect realised another issue induced by the setting-back of columns. Examining Fig. 5.9, Cluster 4, the statistical outlier, contains all the long links; it groups those links that are far apart which link Cluster 3 with Cluster 2 and Cluster 1. In this particular case, these links were formed either because the participants were tracing over or referring to depictions that they drew earlier or when they were concerned with the symmetrical axis of the building.

Results of the NetMeeting Session

Figure 5.12 shows the variations within clusters and the number of links within each cluster. It demonstrates that the five clusters are well separated, with 95 % confidence that there is no overlapping. The statistical outlier, Cluster 5, contains

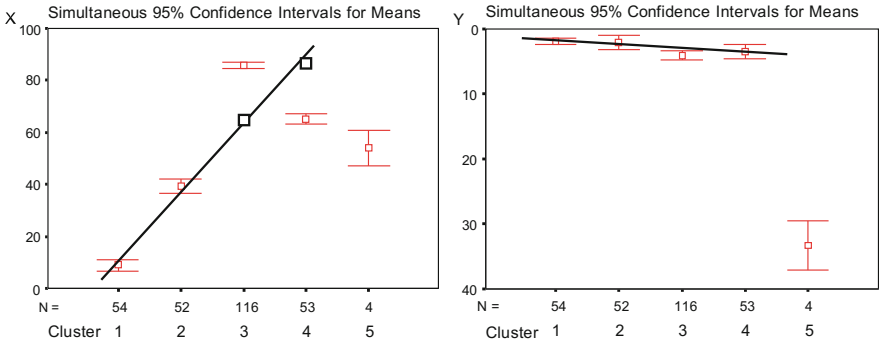

Fig. 5.12 Within cluster variation for the NetMeeting session. Squares were added to represent the clusters in the correct time sequence

only four links. Again, neglecting it, the other clusters reflect the themes of the protocol. Readers should note that the cluster numbers here do not reflect the time sequence; the time sequence would be Cluster 1, Cluster 2, Cluster 4 and then Cluster 3. This is represented by adding two squares in the X mean in Fig. 5.12. This happened because the number of clusters and their labels were automatically generated by the SPSS software. The labels did not carry any notion of time sequence; the software calculated the distances among nodes, grouped and labeled them into clusters without the foreknowledge of how user will interpret the results.

In Cluster 1, with 54 links, they were discussing constraints imposed by NetMeeting—how to scale without references. There were 52 links in Cluster 2; this began with the Architect reading from the brief and continued with the concerns regarding the functional spaces and their relationship. In Cluster 4, with 53 links, the Landscaper introduced another idea, suggesting they take advantage of the level changes in the site, which led to further development by the Architect in Cluster 3, the biggest cluster, 116 links. In this major cluster, the Architect proposed the location of the majority of functional spaces in relation to the site and each other. Cluster 5, the statistical outlier, contains four links between Cluster 5 and the functions in Cluster 2. The Architect was referring to his interpretation of the brief when proposing the location of these functional spaces. The mean value of Y slightly increases towards the end of the session, indicating that links are getting longer.

Comparing the Results of the Two Sessions

Although the face-to-face session has more links, it contains one fewer cluster than the NetMeeting session. This is due to the content; the extra cluster in the NetMeeting session is more about commenting on the technology than designing. So both sessions contain three groups of ideas, but the distribution of the number of links is quite different. The NetMeeting session contains one major cluster at the end with twice the number of links than other clusters. In the face-to-face session, there are two large clusters and one small cluster, and the larger one is in the middle. The statistical outliers contain all the long links; the face-to-face session has a bigger cluster of long links than the NetMeeting session.

The clusters, except the statistical outliers, indicate idea chunks. The size of a cluster indicates its relative importance and the number of clusters suggests the amount of ideas within the period studied. Both sessions have an equal number of ideas chunks but the NetMeeting had one important idea at the end of the first sheet of drawing. The distance (Distance between centroids are usually calculated by $\sqrt{\left(\overline{x}_i - \overline{x}_j\right)^2 + \left(\overline{y}_i - \overline{y}_j\right)^2}$, where $(\overline{x}_i, \overline{y}_i)$ and $(\overline{x}_j, \overline{y}_j)$ are the centroids. However, here the distance is computed by $(\overline{x}_i - \overline{x}_j)$, because the interest is in relating it to the distance between moves, and also the $\overline{y}$ variation is comparatively small enough to be insignificant.) between centroids of subsequence clusters is shorter in the NetMeeting session. In the face-to-face session the distance between Cluster 1 and 2 is 28.3, and the distance between Cluster 2 and 3 is 29.2. So the average is 28.7. In the NetMeeting session the distance between Cluster 1 and 2 is 30.4, the distance

between Cluster 2 and 4 is 25.7, and the distance between Cluster 4 and 3 is 20.5. There is a steady decrease of distance between clusters and the average distance is 25.5. This is not obvious when looking at the design protocols or watching the video. In the face-to-face session, there were interruptions at the beginning and at the end, which slowed the pace, and the distances between the three clusters were even. In the NetMeeting session, the designers were moving more quickly between idea chunks; this is shown by the shortening of subsequent inter-cluster distances. More quickly here means in terms of protocol segments not in terms of time.

Clusters and the distances between them are the basis for new insights in the qualitative understanding of a design session and through multiple design sessions into designing.

5.4 Entropic Measurements

This section presents the results of the entropic measurement of the e-to-face and NetMeeting sessions and the entropic measurement of individuals. It also explores the trends of entropic variation across a design session. How to measure the entropy of a linkograph is described in Chap. 3, Sect. 3.3.2.

5.4.1 Entropy of the Two Sessions

Tables 5.9 and 5.10 show the entropy of the face-to-face and NetMeeting sessions respectively. Forelinks can be seen as initiations and backlinks as responses. As proposed earlier, a higher value of the entropy (labelled H) of forelinks signifies greater opportunity to initiate design moves, and a higher H value of backlinks denotes greater opportunity to build upon previous design moves. The horizonlink entropy indicates the opportunity according to the length of the links; high values of entropy usually indicate a mixture of long and short links, which suggests the cohesiveness and incubativeness of ideas. In the face-to-face session the backlink entropy is slightly higher than the forelink entropy, which indicates a greater opportunity of building upon rather than initiating moves. The NetMeeting session scored the opposite in terms of its entropy measurements, which indicate the initiation opportunity was greater than the response opportunity. These results tentatively match our qualitative analyses of both sessions. In the face-to-face session the designers were at the stage of refining the design, referring to what is already there, whereas in the NetMeeting session they started from the beginning, initiating new

Table 5.9 Entropy of the face-to-face session

Forelinks total H	Backlinks total H	Horizonlinks total H	Cumulative total
34.171	36.693	12.244	83.109

Table 5.10 Entropy of the NetMeeting session

Forelinks total H	Backlinks total H	Horizonlinks total H	Cumulative total
27.865	26.922	11.477	66.264

ideas. However, the difference in entropies is too small to be conclusive. Both sessions have similar horizonlink entropy. Overall, the face-to-face session has higher entropy in all three areas, implying the opportunities are greater in all areas.

These results concur with the link index study; the link indices of the face-to-face and the NetMeeting sessions are 3.05 and 2.88 respectively (Sect. 5.2). However, the cumulative entropy measure shows a larger percentage difference than the link index study (25.4 vs. 5.9 %). This may help to discern subtle differences. Also the link index is a measure of saturation and does not separate the contribution by forelinks or backlinks while entropy measures each separately.

5.4.2 *Entropic Measurement of Individuals*

Chapter 3, Sect. 3.3.2 has described how the entropy of each move is measured for the forelink and backlink. If all the moves contributed by an individual are singled out, the forelink and backlink entropy contributed by that individual can then be calculated. The entropy of individuals is measured to see if it matches their observed role and participation. Tables 5.11 and 5.12 are the forelink and backlink entropy contributions of the various participants. In both sessions the leaders scored higher than their partners in both forelink and backlink entropy. There are two factors that contribute to this: the number of moves and the entropy per move. From our qualitative analysis we know the leaders did most of the drawing, hence they contributed more moves. The leaders also have a higher entropy per move, except for the forelinks of the Landscaper. This is due to the Landscaper's contribution of a new idea—taking advantage of level changes, which is an opportunistic initiation.

Table 5.11 Forelink and backlink entropy by the senior architect and the architect in the face-to-face session

	Moves	Forelink H		Backlink H	
Senior architect	60	21.661	0.361 per move	22.846	0.381 per move
Architect	38	12.511	0.329 per move	13.847	0.364 per move

Table 5.12 Forelink and backlink entropy by the architect and the landscaper in the NetMeeting session

	Moves	Forelink H		Backlink H	
Architect	60	16.582	0.276 per move	17.930	0.299 per move
Landscaper	37	11.283	0.305 per move	8.988	0.243 per move

The individuals' entropy scores reflect their opportunistic contributions. This contrasts with the CM study in Tables 5.2 and 5.4, which indicate that the leaders in both sessions have higher % CM in both forelinks and backlinks.

5.4.3 *Changes in Entropy During the Session*

Observing the linkographs of Figs. 5.5 and 5.6 it can be inferred that the entropy varies across the time line. There are at least two possible ways to measure this change; one uses a fixed time frame as a reference window and the other uses a fixed number of moves as the width of the window to calculate the moving average of the entropy. The latter is used because it is easier to operate and provides a more meaningful comparison. For example, entropy can be calculated within a seven-move window, as in Fig. 5.13. The calculation starts from the first move and advances to the next move, until the window reaches the end. The changes of entropy across the design session can then be recorded. Those links outside the window, not inside the shaded triangle, are disregarded.

The seven-move cut is indicative rather than conclusive. With a large linkograph, using a seven-move window will ignore too many links that make the analysis insignificant. A suitable window width for obtaining meaningful results will be derived theoretically and empirically. By monitoring the change in the entropy, the trend of a design session can be studied and compared.

Determining the Width of Moves Window

The seven-move window is inspired by Miller's magic number seven (Miller 1956). He demonstrated that the chunk of information held in the short-term memory was limited to seven plus or minus two. There are other more articulated memory models, like Paivio's (1986), Bartlett's (1932), and Logie's (1995, 2001), which use the term "working memory" rather than "short-term memory". Baddeley's model of working memory contains three parts: the visuo-spatial sketch pad, the phonological loop, and the central executive. Logie developed Baddeley's model to consider knowledge, long-term memory representation, as a filter that will bias perceptions before getting into the three parts of working memory. It is considered that the content of this memory degrades rapidly; in general it is believed it holds

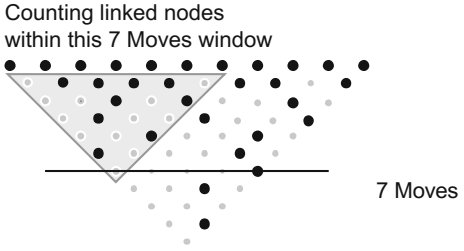

Fig. 5.13 Illustration of using a seven-move window to calculate the entropies

information for about 12–20 s. Important or interesting information will be sustained in the working memory and will trigger further associations in the memory system. As we assume that moves are a selected externalisation of the designers' cognitive processes, in order to communicate with their partners, the cognitive processes that correspond to the moves can be in the working memory or in long-term memory. When these processes are in the working memory, the corresponding moves will have high interconnectivity.

Experimenting with a seven-move window or a nine-move window showed that they were not capturing enough links and the graphs did not reveal any trend. The graphs smoothened as the window width increased. When the moves window was widened to 28 moves, Figs. 5.14 and 5.15 were obtained. For ease of comparison, the value of the entropy was normalised for each window, by dividing it by the window width, 28, to obtain the average entropy per move. With this window width all the disregarded links are those inside the statistical "outliers", as described in Sect. 5.3.2. Also, this window width is slightly wider than the average inter-cluster distance.

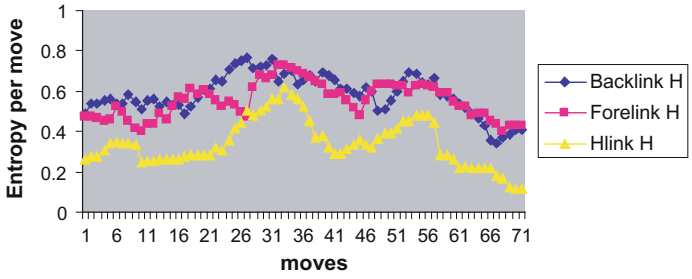

Fig. 5.14 Entropy variations in the face-to-face session, using a 28-move window to calculate entropy

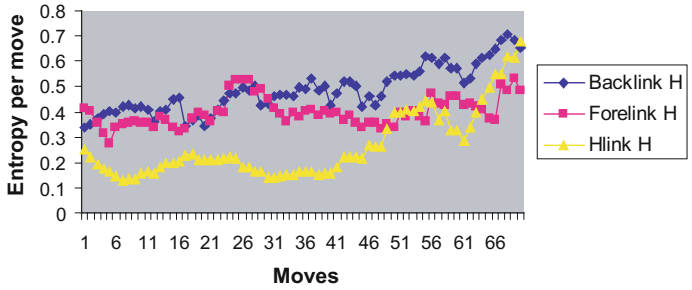

Fig. 5.15 Entropy variations in the NetMeeting session, using a 28-move window to calculate entropy

Observations of Entropy Changes

The trends of the three different types of entropy look similar in their respective sessions but in general the horizonlink entropy scores lower. The overall trend of the two sessions is quite different. In the face-to-face session the entropies peak in the middle of the session, while in the NetMeeting session the entropies peak at the end of the session. This complements the cluster analysis; the clusters that have the most links receive the highest entropy.

To further investigate the trends the backlink entropies were selected and fitted by a polynomial function. They were assigned to an array in MatLab and its supervised polynomial fit function was used to obtain a fourth-degree polynomial, Figs. 5.16 and 5.17. Since the scale of the entropy axis of Figs. 5.16 and 5.17 was

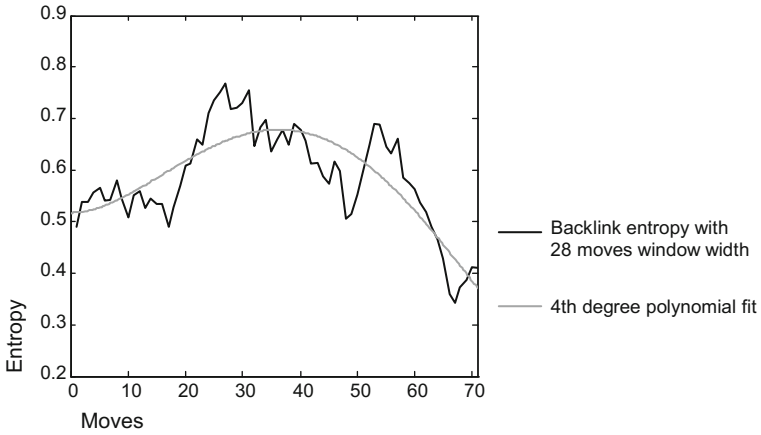

Fig. 5.16 Polynomial fit of the entropy variations in the face-to-face session

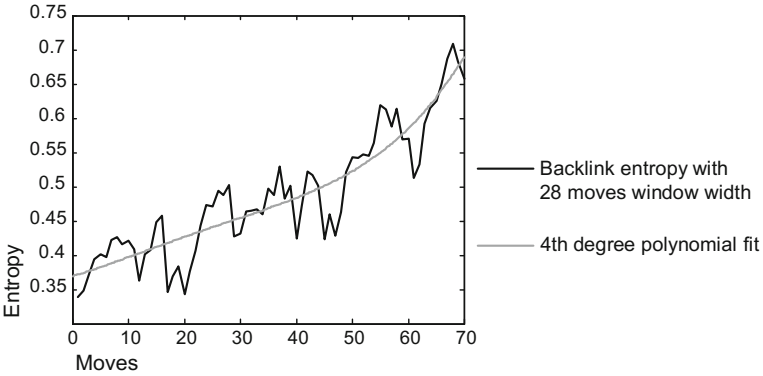

Fig. 5.17 Polynomial fit of the entropy variations in the NetMeeting session

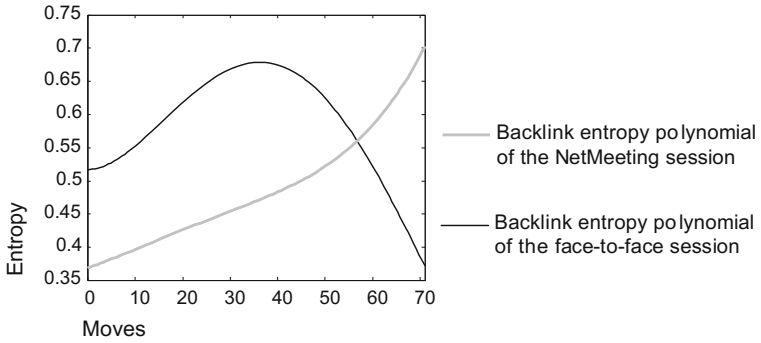

Fig. 5.18 Plotting the backlink entropy polynomial fit of the two sessions with the same scale

different, the polynomials were re-plotted with the same scale in Fig. 5.18 for comparison.

The form of the two polynomials is very different. The rate of entropy variation (the slope of the curve) of the NetMeeting session is always positive, while in the second half of the face-to-face session the rate of entropy variation is negative. Figure 5.19 plots the rate of the change in entropy of the two sessions. The face-to-face session has a higher backlink entropy, while the NetMeeting session has a higher positive rate of change in entropy. This is confirmed by using adaptive Simpson quadrature in MatLab to calculate the areas under the curves in Fig. 5.19. The areas are 0.032 for the face-to-face session and 0.162 for the NetMeeting session. This can be seen as the signature of a design session.

This entropy variation rate can be correlated to the idea chunks distance in Sect. 5.3.2. A positive rate means the ideas chunks are getting closer and closer as the design move along and a negative rate means the ideas chunks are getting further apart as time goes by.

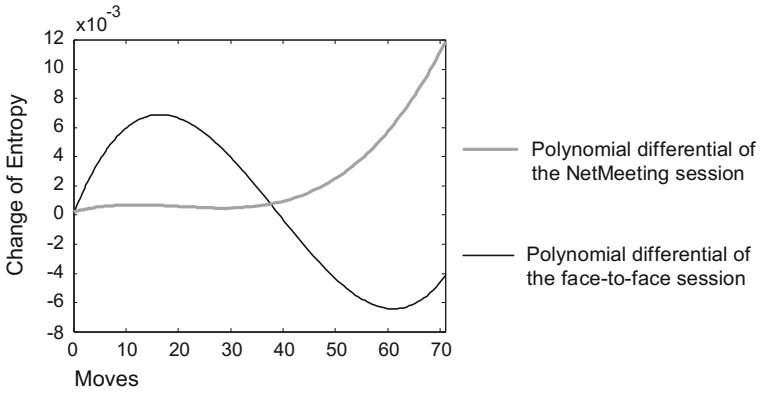

Fig. 5.19 The polynomial representing the change of the backlink entropy in both sessions

5.5 Findings and Discussions

In this study the proposed methods of studying design protocol were applied to two design sessions. In both sessions the designers were working together on the same artefacts simultaneously in two different media. In the face-to-face session they used traditional paper and pencil, whereas in the NetMeeting session they used a computer-mediated simulation of distance collaboration by a shared whiteboard and video-conferencing tool. There were more interactions between the designers, with gestures and reference to drawings, in the face-to-face session. Many of the verbal communications were not complete, because of the tacit knowledge. In the NetMeeting session the turn-taking in conversation was more orderly and complete.

Standard descriptive statistics were able to describe the shape of a linkographs and in our case study they were able to pick up some of the differences in the design processes, such as the lengths of the links and the position of intensive activities. The preliminary results using clustering and entropy were promising. Clusters automatically generated by commercial software were able to map onto the actual design activities, hence the semantics of a cluster could be labelled. The statistic outliers contained long links that connected other clusters. Entropic measurement matched the qualitative analysis. Traditional studies of linkographs have used link index and critical moves to analyse the design protocol. In the two case studies, the total cumulative entropies agreed with the link index with a different magnitude.

From the investigation of entropy variation, it can be observed that the two sessions produced very different shapes of move-entropy graphs. Further investigation is required for discerning the meaning of this signature. It is likely that a positive rate of change of the move-entropy graphs implies a diverging process, since the idea development opportunity is continually increasing. It is likely that a negative rate of change of the move-entropy graphs implies a converging process, since the idea development opportunity is continually lessening. We explore this further in the next chapter.