OBSERVATIONS FROM AN EXPERIMENTAL STUDY OF COMPUTER-MEDIATED COLLABORATIVE DESIGN

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Abstract. The use of computer technology in design practice is moving towards a distributed resource available to a team of designers. The development of software to support designers has been based largely on the assumption that there will be a single person using the software at a time. Recent developments have enabled the feasibility of software for two or more simultaneous users, leading to the possibility of computer-mediated collaborative design. Research in integrated CAD, virtual design studios, and design protocol studies provide the basis for a formal study of computer-mediated design. We develop an experimental study of computer-mediated collaborative design with the aim of collecting data on the amount and content of design semantics documented using computer applications when designing alone as compared to designing collaboratively. The experiment includes the definition of an hypothesis, aim, methodology, data collection and coding schemes. The experiment and some preliminary observations are presented, followed by directions for further research.

1. Introduction

Design projects require a collaboration of designers, a coordination of the information flow between them and a synchronisation of the tasks they perform. The development of software to support designers has been based largely on the following assumptions:

- isolated desktop personal computing, and
- the software is used by one person at a time.

These assumptions influenced the user interfaces and design information representation schemes. The development of client/server architectures, desktop video conferencing, groupware, and the availability of the Internet has changed our expectations for design software to allow multiple designers to interact in a computer-mediated environment. The implications of these developments include the possibility of computer-mediated collaborative design (CMCD), where participants cluster around an electronically-supported work environment as an alternative to the collaboration around a bunch of drawings, a cardboard model or at a meeting that is largely paper-based.

On the other hand, the application of computing technology in design practice is moving towards a distributed resource available to a team of designers. In addition to CAD, designers now use a variety of information processing software including databases, spreadsheets, data analysis and simulation programs, and Internet access facilities.

The use of computing technology in design practice has shown that

- very little is understood about the phenomenon of collaboration within a distributed computer-networked environment, and
- there is a need for an appropriate computer representation for handling design documentation in an electronic format that enables effective collaboration among the professionals.

To address these issues requires the development of methods for modeling designers' collaboration and analysis of information dynamics and information handling in collaborative sessions.

In this paper we present a formal approach for conducting experimental studies of CMCD. It includes the design of an experiment and a technique for collecting and analysing data from computer-mediated collaboration. The initial experiment is focused on the type and content of the information recorded in a collaborative design session. The main goal is to compare the amount and content of design semantics in documents created by both individual and collaborative designers using computer applications. The key issue in understanding the results of the experiment is the coding and analysis of the data collected. The paper presents the coding scheme in which we distinguish the information that carries design semantics from the non-semantic design information in the documentation. The summary discusses what has been learned from the experiment so far and identifies future directions for such research.

2. Background

The experimental study makes some assumptions about the meaning of design semantics and applies methodology from design protocol analyses. This section gives a brief review of relevant work in these areas and provides the basis for our observations and conclusions in Section 5.

2.1. COMMUNICATING AND CAPTURING DESIGN SEMANTICS

Collaborative design, whether it is computer supported or not, deals with communicating and sharing design information. Computer-supported design adds a means for storing design semantics through all steps of the design process.

The research community has developed several representation paradigms to capture design semantics, justifications of design decisions, and properties associated with performance and behaviour of designs. Typically, the object-oriented paradigm is applied to integrate information across CAD systems by using a schema for representing information relevant to design. An example of such a schema is the design prototype (Gero, 1990), where each class of design objects is characterised by its function, behaviour, and structure. The project data is typically stored centrally and accessed by separate programs, as in Fenves et al. (1994). Another approach is to allow users to link their interpretations to the CAD objects thereby capturing multi disciplinary interpretations (Clayton et al., 1994). The issues raised by data modelling for integrated CAD are relevant to CMCD because CAD drawings alone are insufficient to communicate the design semantics needed for collaboration. However, the implications of CMCD go beyond the data models, where the focus is on exchanging information between computer programs, to the development of a shared understanding, where the focus is on how human designers communicate through the computer.

2.2 COLLECTING AND ANALYSING DATA

Protocol analysis has been used for coding and understanding design sessions since the early 1970s. As described in Akin and Lin (1994), the relationship of two forms of data, verbal-conceptual and visual-graphic, constitutes a major issue in building a coding scheme. Usually, data are collected in two ways: audio recorded and a sort of graphic recording. This could be both video recording and drawings on paper.

Ericsson (1985) reports a wide range of interpretations, techniques and analyses of protocols, dividing them into selection of information, coding scheme for behaviour, aggregations of data by episodes, solutions steps, processes or individual differences. Methods for protocol analysis (Ericsson, 1985) are encoding vocabulary, segmenting and encoding processes, automation of encoding and level of analysis.

The coding scheme definition is an issue which plays a major role in data analysis. A report on analysis of design processes is presented by Takeda et al. (1994) and Umeda et al. (1990). They define a set of three concepts in analysing design protocols: function, behaviour and structure (FBS). Function represents “a description of behaviour aspects abstracted through recognition of behaviour for utilisation” (Takeda et al., 1994, p.84). Behaviour is defined as “sequential change of states of objects” and structure as a level represented by entities, attributes of entities and relations among entities. The FBS structure of analysis is a first step taken for a definition of coding scheme in design protocols.

A different coding scheme is reported in Purcell et al (1994), in which each event in a design episode is categorised over three broad classifications. These three classifications are:

(1) *problem domain: level of abstraction*, in which designers are considering the complexity of the problem and trying to analyse relations between multiple aspects of the same design;

(2) *problem domain: FSB*, which treats function as intended purpose, behaviour as the response of the object to its environment, and structure as the physical description of the design, and

(3) *strategy*, which codes the design activity step by step as problem analysis, solution proposal, solution analysis, and identification of relevant knowledge.

Different coders might produce different coding results. For this reason, a method of agreement must be followed. The Delphi Method tries to give a structure to the coding process, in order to reach an agreement about the final coded protocol (Linstone and Turoff, 1975). Coding is performed by two independent coders, followed by an arbitration process. "Delphi may be characterised as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff, 1975, p. 3).

Other investigations on protocol analysis have been done by Günter, Frankenberger and Auer (1994), Visser (1994), Baya et al. (1994), Trousse and Christiaans (1994), Popovic (1994). The coding schemes for each study have been developed specifically to fit the desired results. These studies provide the basis from which we have developed a coding scheme for studying CMCD.

In our study of CMCD we borrow the idea of coding and analysing the data of the collaborative session, but we do not consider the data to be the verbal utterances of the subjects. Since we are not trying to reconstruct the collaborative design *process*, but to understand how the designers document their designs differently when collaborating, the verbal utterances would not provide the correct data. Rather, we have taken the data to be the information that has been saved as working files on the computer to document the design.

3. An experimental study of computer-mediated collaborative design

This experimental study of computer-mediated collaboration is based on the methodology of protocol studies and analytical coding schemes. A major point of departure in the study, when compared to other protocol analyses of designers, is that we are not trying to understand the collaborative design *process*, but to understand the difference in the documentation that results from a designer working alone as compared to designers involved in CMCD. In this paper we describe the results of the first series of experiments which aim to identify the amount and content of semantic information recorded during a CMCD session as compared to a computer-aided individual design session.

3.1 STRUCTURE VS. SEMANTICS

The structure of a design is generally described by its geometry. Geometry is that part of a design in which a shape is formalised. Formal representations of geometry provide the logic and expressiveness of a mathematical language. For example, space configuration, orientation of the elements and thickness of walls are typical properties formalised in a geometric representation.

However, geometry does not say anything about the purpose of the structure until the functions of design elements are described explicitly. Moreover, as in mathematical formalisms, geometric representations are abstract objects, out of the context of a particular design. Thus, we face a situation where geometric representations allow various interpretations, and can even be meaningless. Due to a lack of standardised graphic representations for all possible geometries and misunderstanding through the different use of symbols, drawings may communicate no, or worse, incorrect semantics. We might say that often there is a gap between geometry and semantics, which cannot be ignored.

The semantic representation includes “reasons of choice”. Semantics are a fundamental part of a collaborative session. Whereas image and shape can be visualised and pointed out with cursors, purpose, function and performance cannot be indicated until they find a formalisation in a drawing, i.e. until they are described explicitly.

In computer-supported design environments, the structure of a design is created by CAD systems and drawing and image processing programs. Based on the facilities for manipulating geometry, the interface of the above mentioned packages provides primitives for producing drawings that focus on the geometry. For this reason, these systems will be considered as lacking facilities to easily represent this semantic level, which we propose is an important part of design documentation. Although this is a major problem of any collaborative session, in a physical collaboration the semantic level can be expressed personally through explanation. In a CMCD session, the semantic level has to be engaged with computer interfaces and then restricted by their "bandwidth" and particular expressive facilities.

Images and text are complementary information representations in design documentation. Though approaching different cognitive and communicating mechanisms, in architectural design they always work simultaneously. It is almost impossible to generate a protocol for each one of them, without it being affected by the other. However, in order to study the documentation from a CMCD session, we need to trace an imaginary line between them and map them onto *structure* and *semantics*.

For the purposes of the study, we define structure to be the explicit geometric representation of the design and semantics to be the explicit representation of the purpose of a structural element or composition.

3.2 THE EXPERIMENT

The experiment includes two design sessions for each participant. In each session, designers document their designs using the computer. In the first session we established base data for each designer by asking him to design alone. In the second session we asked two designers to design collaboratively. We ran the experiment for three teams of two designers and report the results.

During session 1 each designer is asked to work on Design Problem 1 (DP1) on their own for approxiamtely two hours. During session 2, a pair of designers is asked to collaboratively solve Design Problem 2 (DP2), again for approximately two hours. DP2 is a similar type of problem to DP1, but with a different brief. To avoid the influence of different collaboration styles, in session 2 each of the two designers (A and B) in the pair were assigned a particular role. Designer A was asked not to make changes to the design description directly. Through the means of video conferencing designer A could only instruct designer B to document these changes. Consequently designer B was responsible for documenting design information. However, designer B was not simply an operator. He had equal rights with designer A for discussing, suggesting, modifying, accepting or rejecting design solutions. In every team the role of designer B was granted to the designer with better computer skills. Such separation aimed at minimising the influence of computer interface on documenting design information.

An observer recorded the session. We did not examine the process of collaboration since we wanted an initial idea about what part of the semantic information reaches the design documentation. The observer was allowed to reply to questions about the brief, if needed, during the experiment. In addition, the observer examined the needs of computer support in sessions 1 and 2. The observer was also responsible for helping to overcome technical problems that occurred during the experiment.

3.3 TECHNICAL SUPPORT

Each designer's workplace included a Silicon Graphics Unix workstation and a Macintosh personal computer. The video conference software was on the Silicon Graphics Indy and the multi-user work environment was on the Macintosh. We decided to use two computers rather than one so that the designers had a choice of technology that suited them personally and to alleviate the problem of lack of screen space.

The video conferencing software (InPerson) provided the video, audio, and shared whiteboard facilities. Inperson’s whiteboard is organised as a notebook with multiple pages and different cursor icons for each participant. The multi-user work environment was Timbuktu on the Macintosh. On the Macintosh designers had multi-user access to a word processing program, a spreadsheet, a simple drawing program, a CAD system, 3D modeller, a simple database and a Web browser.

3.4 DATA COLLECTION AND THE CODING SCHEME

During each session data has been collected by the observer taking notes on the general progress of the design process and by recording the windows of the design software as snapshots every 5 minutes. The recording has been done unobtrusively. The detailed “visual” description of the design is based on window snapshots and final documented designs as represented in the files created by the designers. An example of a documented design is presented in Figure 1.

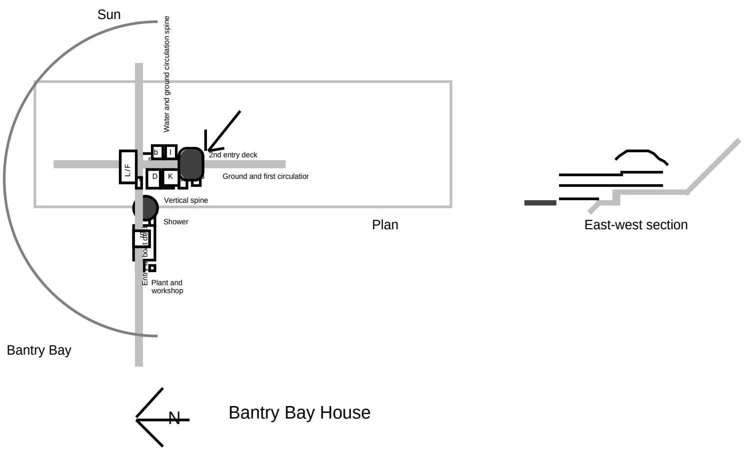

Figure 1. Example of a documented design

We developed a two level coding scheme: one using a data-driven approach and the second a hypothesis- or expectation-driven approach. Using the data-driven approach, the elements of the documented designs have been counted and categorised according to their text and geometry content. Using the expectation-driven approach, we classify the categorised elements as “semantics” or “structure”. As stated before, we define the semantics elements as those which document the purpose of the design element and the structure elements to be those that document the geometry of the design element.

3.4.1 Level 1 Coding

The first level of the coding scheme segments the data into elements of the documented designs. These data unis are categorised using the following terminology and guidelines:

LG (Labeled Geometry) - the information unit consists of geometrical contour (closed or open) and a label attached to it. Such an information element communicates the geometry and possibly the semantics of the design element. Since graphical labels can add semantics, equivalent to the meaning assigned to the label in the list of keys to the drawing or in preliminary agreement between designers, we distinguish the following types of labels:

- textual
- single letter or digit
- meaningful string of letters or digits (one or more words)
- graphical label
- icon (graphical symbolic label
- pattern filling
- color, different from the default fore- and background color pair
- line pattern, density and/or width

NLG (Non-Labeled Geometry) - the information unit consists of geometrical contour (closed or open) without any labels and has been realised in the default foreground-background color attributes.

Te (Text) - the information unit is composed from one or more strings of characters which belong to predefined alphabet. By this definition textual information include both numerical and text data.

To (Token) - the information unit consists of a context-free symbolic pattern made by either a geometric form or a set of words.

3.4.1 Level 2 Coding

The data units identified in the level 1 coding are classified in clusters of “structure only”, “both structure and semantics” and “semantics only”, using the following guidelines:

Structure (only). This category includes the information concerned with geometry, location on the site, orientation, composition. This category incorporates NLG-, LG- and To- elements.

Semantics & Structure (both). This category comprises the information recorded by designers that is related to the purpose or intended use of design element(s). For example, the purpose of a room may be to serve as a bedroom, laundry, office, etc., the purpose of a wall may be to separate two parts of the house, the purpose of an entrance may be to provide an access to a particular part of the house. This category of information includes elements of LG-type.

Semantics (only). This category comprises the information recorded by designers that is related to the purpose of a reserved space, which has not been assigned particular geometry. This category of information includes elements of Te-type[1].

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[1] In general, the textual explanations of spatial configurations can be classified in the Structure category. However, we didn’t find such descriptions in the analysed

The common LG-elements represent the geometry of the design and the purpose of this geometrical form. However, this does not mean that all LG elements enter the category of structure and semantics. There are certain LG elements, which carry no semantics related to the purpose of the design. For example, an east-west elevation as a labelled geometry element does not communicate any semantics related to the purpose of the elevation.

The coding scheme is illustrated in Figures 2 and 3 with examples from the data collected. Figure 2 presents a series of LG information units. Illustration (a) shows how the designer documented the relative size and purpose of the laundry room. Similarly, illustration (b) shows the room with purpose "S" ("Study"). Illustration (c) shows the location of the vertical spine and the shower. Illustrations (a), (b) are examples of LG with textual labels (string of characters and single letter, respectively). Illustration (c) contains two LG elements. One of these elements is marked "heavily" both with textual and graphical labels (textual label is "Vertical spine", the graphical label is the pattern filling). In this case both the textual label and the pattern filling are increasing the richness of semantics. In the "undocumented" key to the drawing this particular pattern indicates the vertical direction. Therefore, together with the textual label "Vertical spine" it carries the semantics of the purpose of the element and its particular form (cylindric). In general, in the "heavily" labelled elements each of the labels may carry its own meaning. Illustration (d) shows a set of LG information units, documented by designer. Textual labels give an idea about the purpose of particular "boxes".

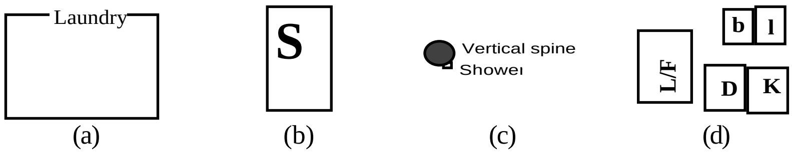


Figure 2. A representative sample of LG (elements from documented designs)

Figure 3 illustrates other types of information. Figure 3(a) is an example of NLG, which is a scaled copy of the large rectangular form in Figure 1. Without additional explanation from the designer it is not clear what is the purpose of this element. Figure 3(b) includes an LG element that is classified in the Structure (only) category. In this case the label is attached to the whole composition of geometric elements. Figure 3(c) presents a combination of LG and textual information. In this example the two textual elements ("Bathroom" and "Master Bedroom") indicate the purpose of the design elements without allocating a particular space, i.e. without geometric layout. They are classified in the Semantics (only) category. The only spatial information is the relative location with respect to the other

documents, therefore, in this study we have placed them only in the Semantics category.

design elements. The fragment of drawing (d) has two LG entities and one NLG entity. Figure 3(e) illustrates the idea of the Token. For example, replacing the word “Sun” by its symbol (for instance, ☼) does not change the meaning of the information. Figure 3(f) is another example of a token where designers used a widely accepted cartography composite symbol which shows the direction of North.

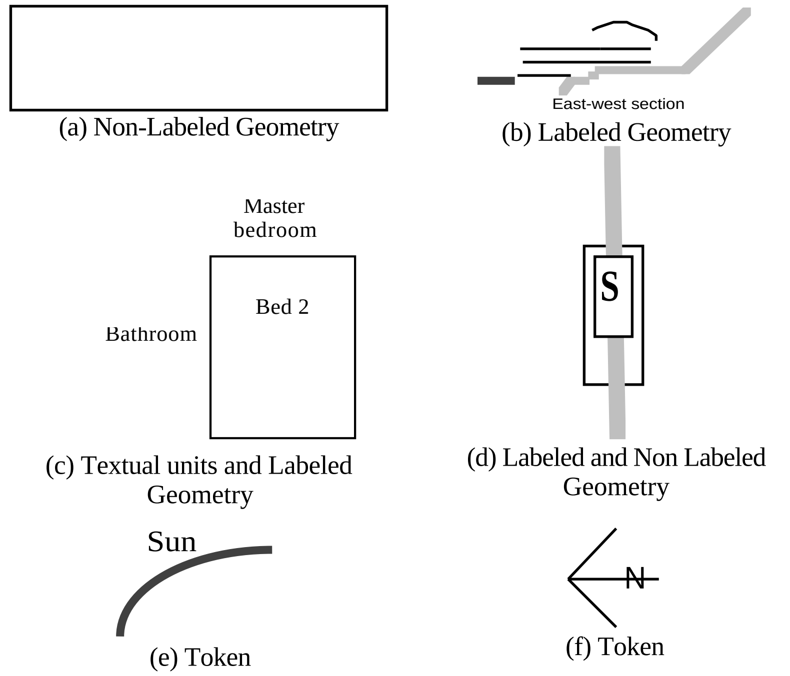


Figure 3. Different categories of information from a documented design

4. Data analysis

The objective of the analysis of the experimental results is to compare the amount of semantic information recorded by the designers during computer-mediated design sessions to design sessions when they worked alone. We are interested in the nature and “usefulness” of stored electronic design documents, rather than in ranking the designs as solutions. Taking into consideration that these are initial results, it is necessary to stress that this analysis does not aim to produce final conclusions but to provide the platform for further experimental study of CMCD. Though we deal with a limited amount of experimental data, we found unexpected results, that is, very little semantic information is recorded at all and less is recorded during a collaborative session.

4.1 NOTATION

For further consideration we distinguish three teams $\{T_1, T_2, T_3\}$ of two designers each, whom we refer as $\{d_{ij}; i = 1,2,3; j = 1,2,3\}$, where i is the team index, j is the designer's index. They produced nine documented designs:

- six in non-collaborative sessions, denoted as $\{D_{ij}; i = 1,2,3; j = 1,2,3\}$, where *i* is the team index, *j* is the designer index;
- three in collaborative sessions, denoted as $\{D_i; i = 1,2,3\}$, where i is the team index.

The notation scheme is presented in Table 1.

Team	T_1		T_2		T_3	
Designer	d_{11}	d_{12}	d_{21}	d_{22}	d_{31}	d_{32}
Design Document (non-collaborative session)	D_{11}	D_{12}	D_{21}	D_{22}	D_{31}	D_{32}
Design Document (collaborative session)	D_1		D_2		D_3	

Table 1. Notation key

Before continuing with the analysis of experimental material we provide a more comprehensive picture of the spectrum of the documented designs.

4.2 DOCUMENTED DESIGNS

Designers from team T_1 and T_3 preferred, both when working separately and collaboratively, to use a simple graphic editor, that gives them facilities for 2D sketching and word explanation. The documented designs D_{11} and D_{12} in the non-collaborative CMD sessions are presented in Figures 1 and 4, respectively. An implicit 3D geometry is documented by the means of multi-layer structure of the design document D_{11}. This is an example of the use of the advantages of computer media as a 2D representational tool. Therefore the analysis of this document in some sense was similar to an archaeological excavation: it required sequential removal and analysis of each layer. Figure 1, in the previous section, shows all layers of the documented design of D_{11}. In contrast, designs D_{12} (Figure 4), D_{31} and D_{32} are single layer schematic sketches.

The members of team T_2 preferred to use CAD and 3D solid geometric modeling. Advances in computer graphics have stimulated an interest in using visualisation as a means of man-machine communication, but it seems that this does not stimulate the designer to document more semantic information. Figure 5 is an example of a documented design (of a house!) using “the language” of the 3D-modeller. At first glance, it stands out that the “high concentration” of geometry lacks specific semantic meaning.

During the collaborative session, the designers operate the shared whiteboard for communication and presenting the design schemes. The designers of teams T_1 and T_3 kept the same style in designing, creating the 2D sketches on the shared whiteboard. These drawings constitute the design documents D_1 and D_3. Team 2 used the shared board for documenting more information in addition to the CAD drawing they produced. Part of the final document D_2 is presented on Figure 6, showing both the information on the sketching board and the CAD model.

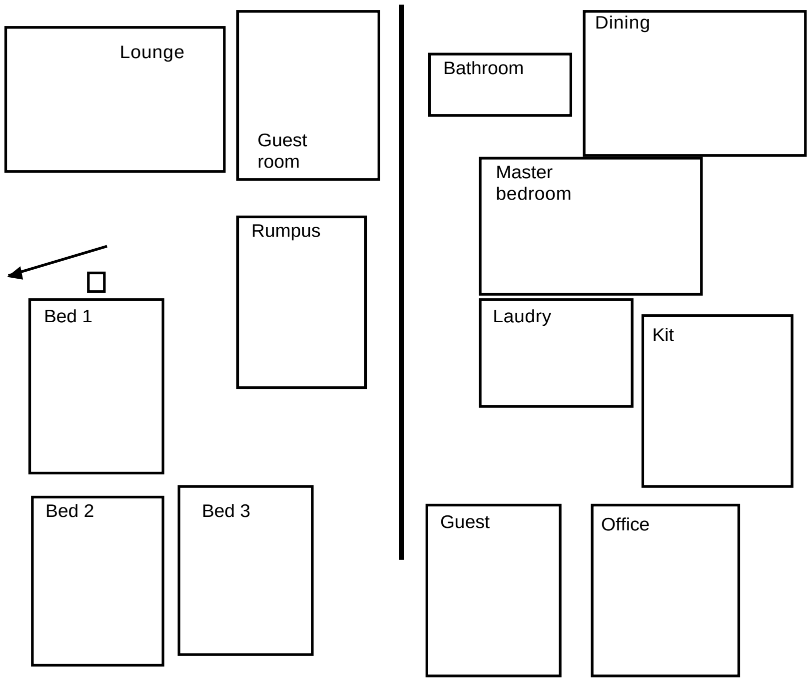


Figure 4. Documented design D_{12}

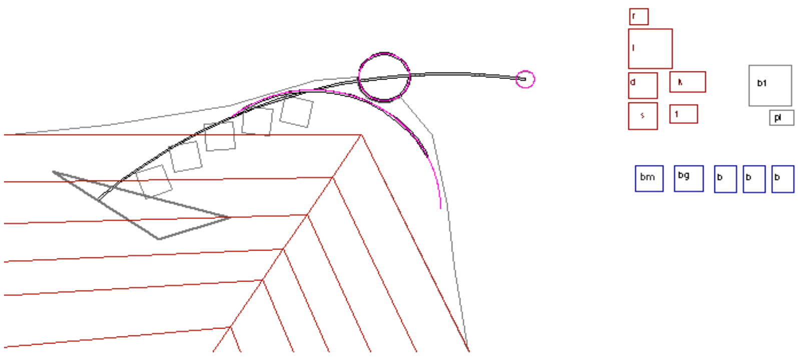
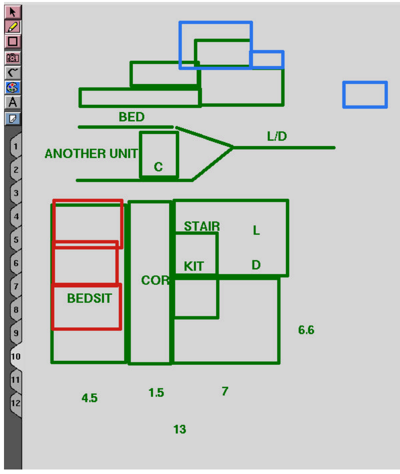
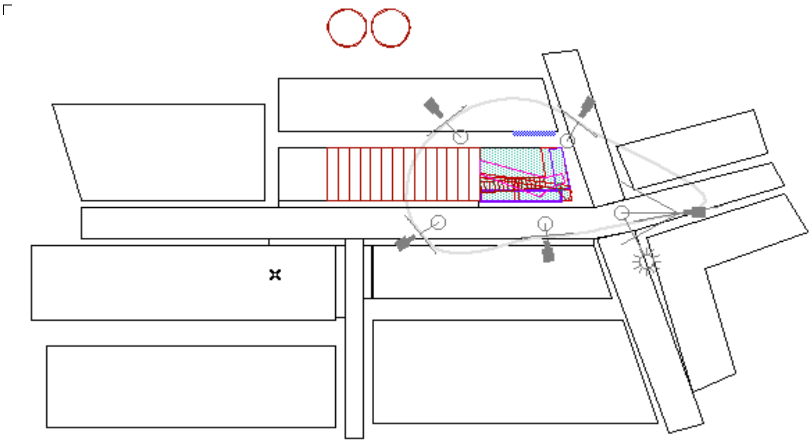


Figure 5. Part of the documented design D_{22} (CAD drawing)

(a) “Whiteboard” plan



(b) “Whiteboard” plan



(c) CAD drawing of the final design

Figure 6. Part of the documented design D_2

4.3 CODING AND DATA PROCESSING

Each document has been double coded according to the guidelines of Coding 1. The coders then compared their results and achieved consensus on the classification of every information chunk, thus eliminating the random component of the errors. The consistent output for the non-collaborative and collaborative sessions is presented in Tables 2 and 3, respectively. The total amount of these information entities is denoted by I_T., i.e.

$$I_T = I_{LG} + I_{NLG} + I_{Te} + I_{To} \qquad (1)$$

where $I_{LG}, I_{NLG}, I_{Te}, I_{To}$ denote, respectively, the amount of LG, NLG, Te and To information units.

Design	D_{11}				D_{12}				D_{21}				D_{22}			
Coding 1	LG	NLG	Te	To	LG	NLG	Te	To	LG	NLG	Te	To	LG	NLG	Te	To
I	23	12	2	3	13	2	0	1	1	56	0	9	13	24	0	0
I_T	40				16				66				37			

a.

Design	D_{31}				D_{32}			
Coding 1	LG	NLG	Te	To	LG	NLG	Te	To
I	52	3	0	0	20	5	5	2
I_T	55				32			

b.

Table 2. Summary of Coding 1 for designers working alone

Design	D_1				D_2^*				D_3			
Coding 1	LG	NLG	Te	To	LG	NLG	Te	To	LG	NLG	Te	To
I	2	34	2	4	28 (38)	29 (14)	0 (0)	3 (0)	26	36	0	2
I_T	42				60 (52)				64			

Table 3. Summary of Coding 1 for designers working collaboratively

Analysing document D_2 we separate the schematic documentation on the whiteboard, which complements the description of the design from the CAD drawing. This step has been done to avoid the bias of the results, due to the large amount of geometrical information on the CAD drawing, that duplicates the geometry in the whiteboard files. Thus, the categorisation of D_2 is based on the data recorded in the whiteboard file. In the parentheses are listed the results of the categorisation of the elements of the CAD drawing in document D_2.

For each document the output of Coding 1 has been double coded according to the guidelines of Coding 2. Then, similar to Coding 1, the coders compared their results and achieved consensus on the classification of

* Design document D_2 includes sketch drawings stored in InPerson Whiteboard format file and CAD drawing. In parantheses are presented the results for the CAD drawing part of the documentation.

every information chunk. Coders were allowed to look at the corresponding design brief during the coding.

Thus if we denote by I_F, I_P and I_B the amount of entities related only to the **F**orm (Structure) category, only to the **P**urpose (Semantics) and to **B**oth (Structure & Semantics) categories, respectively, then for every document

- the total amount of structural information is estimated as $I_{str} = I_F + I_B$
- the total amount of semantic information is measured as $I_{sem} = I_P + I_B$
- the relative amount of particular kind of information is measured as $I' = I \ / \ I_T$, where label $\{F, P, str, sem, B\}$ and I_T is estimated following expression (1).
- the relative difference between the amount of structural and semantic information is estimated as $\Delta I' = I'_{str} - I'_{sem} = I'_P - I'_F$.

The results of Coding 2 for the non-collaborative and collaborative sessions are shown in Tables 4 and 5, respectively. In the parentheses are listed the results of the coding of the CAD drawing in document D_2.

Design	D_{11}			D_{12}			D_{21}			D_{22}			D_{31}			D_{32}		
Coding 2	F	B	P	F	B	P	F	B	P	F	B	P	F	B	P	F	B	P
I	16	22	2	3	13	0	65	1	0	24	13	0	3	52	0	7	20	5
I'(%)	40	55	5	19	81	0	98	2	0	65	35	0	5	95	0	22	62	16

Table 4. Summary of Coding 2 for designers working alone

Design	D_1			D_2*			D_3		
Coding 2	F	B	P	F	B	P	F	B	P
I	38	2	2	38 (52)	22 (0)	0 (0)	38	26	0
I'(%)	90	5	5	63 (100)	37 (0)	0 (0)	59	41	0

Table 5. Summary of Coding 2 for designers working collaboratively

The estimates of structural and semantics information together with the Δ-values for each document are given in Table 6.

Team	T_1					
Design	D_{11}		D_{12}		D_1	
Categories	Structure	Semantics	Structure	Semantics	Structure	Semantics
I'(%)	95	60	100	81	95	10
$\Delta I'$(%)	35		19		85	

* In the parantheses are the results for the CAD drawing part of document D_2.

a.

Team	T_2					
Design	D_{21}		D_{22}		D_2	
Categories	Structure	Semantics	Structure	Semantics	Structure	Semantics
I'(%)	100	2	100	35	100	37
$\Delta I'$(%)	98		65		63	

b.

Team	T_3					
Design	D_{31}		D_{32}		D_3	
Categories	Structure	Semantics	Structure	Semantics	Structure	Semantics
I'(%)	100	95	84	78	100	41
$\Delta I'$(%)	5		6		59	

c.

Table 6. Structure and semantic information

5. Observations and conclusions

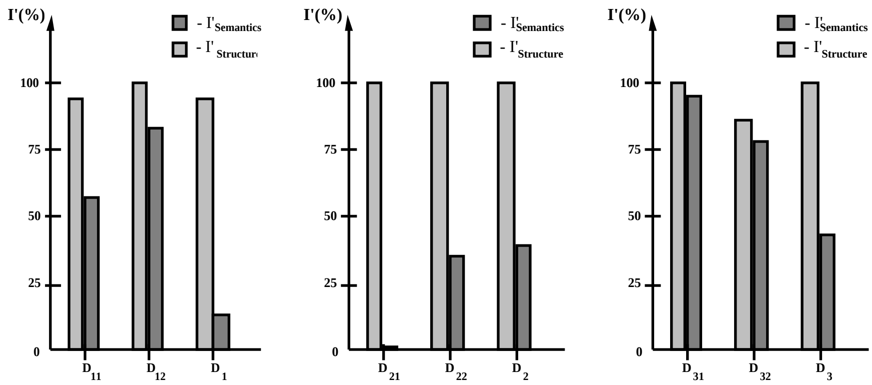
We have presented an experiment and the results of coding and analysis for comparing the amount of semantic information recorded in a CMCD session to a computer-mediated session in which designers work alone. Here we discuss our observations in terms of the amount and comparison of documented semantics, the coding scheme, and the experimental methodology.

5.1. COMMUNICATING, CAPTURING AND STORING DESIGN SEMANTICS

The interpretation and understanding of the design purpose is a function of semantic information. During the collaborative sessions design semantics was communicated on the shared whiteboard and through the audio and video channels of the conferencing system. Designers included part of the information on the whiteboard in the final document. When considering the amount of documented design semantics, we found that both the single designer and the collaborative designers recorded very little semantics. In summary we found:

In all of the nine design documents the amount of semantic information is less than the amount of geometry.

These results, based on Structure/Semantics categorisation presented in Table 6, is illustrated in Figure 7. In this context Team 2 (Figure 7(b)) is the “leader”, focussing on 3D visualisation without labels.



a. Team 1 b. Team 2 c. Team 3

Figure 7. Comparing documented semantics and structure for all designs

The first session of the experiment provided the base data for comparing the amount of documented design semantics for a designer working alone with that same designer working collaboratively. To be able to compare individual designers d_{ij} we introduce a corresponding *semantic ratio* λ_{ij},

$$\lambda_{ij} = \frac{I'_{sem}\left(D_i\right)}{I'_{sem}\left(D_{ij}\right)} \tag{2}$$

where $I'_{sem}\left(D_i\right)$ and $I'_{sem}\left(D_{ij}\right)$ are the relative estimates of semantic information in the documents, produced by designer d_{ij} during the collaborative and non-collaborative sessions. The estimates of the corresponding semantic ratios are shown in Table 8.

Designs	D_{11}	D_{12}
D_1	0.17	0.12

a.

Designs	D_{21}	D_{22}
D_2	18.5	1.06

b.

Designs	D_{31}	D_{32}
D_3	0.43	0.53

c.

Table 8. The semantic ratios for every team member.

If the value is less than one then it means that more semantic information has been documented in non-collaborative session. If the ratio is more than one than it means that during the collaborative session more semantic information has been documented.

Four of the designers recorded significantly more semantic information during the non-collaborative session. The two designers in T_2 recorded more semantics information during the collaborative session. The semantic ratios for the designers in team T_2 are partly explained by the fact that in both sessions semantic information has been documented by designer d_{22}, that is the reason why his semantic ratio is so close to one! He determines the amount of semantic information recorded by the team during the collaborative session. Consequently, this is the reason why the semantic ratio of d_{21} drops out of the tendency. Though the data is not enough to derive significant conclusions, we observe that:

Designers tend to document more information related to the purpose of their design during the non-collaborative sessions than during collaborative work.

These observations are influenced by the duration of the design sessions and the use of 2D drawing tools and 3D CAD. Research on the content of design semantics and the representation of the semantics as part of the CAD documentation was not relevant in our experiment due to the nature of the design task. The designers did not document the designs to a significant level - in fact the coders had difficulty in understanding anything at all about the documented designs. These observations indicate that isolated, short duration, collaborative design tasks do not result in the documentation of design semantics. This conclusion has implications on the level of support needed in a collaborative design environment for documenting design semantics.

5.2 COLLECTING AND ANALYSING DATA

The data we collected in this experiment was the documented designs. Additional data that was not collected and analysed was the verbal utterances of the designers. A significant amount of design semantics was communicated in conversation. Based on our observations of the designers while collaborating we found:

Due to the intensive information exchange via video conferencing between the parties during a CMCD session, a valuable amount of the semantic information is left undocumented.

Designers described their design semantics verbally, through video and audio channels, and this information is not included in the final design document. These observations bring to the front the issue of capturing the missing semantic information by recording the audio and video information designers exchanged during the session. In that case in contrary to the static information recorded in the design document we have to deal with dynamic transfer of information. That requires the development of an extension to the above presented coding scheme and a revision of the results to include the communication of design semantics in addition to the documentation of design semantics.

5.3 METHODOLOGY

The methodology of establishing two sessions for each designer to compare the effect of collaboration on design activity is a general methodology that can be applied to other studies. We found that by establishing base data for each designer, we could isolate the effect of collaboration on the resulting design documentation. Other applications of this methodology could be the study of the design process, the effect of negotiation, and the establishment of design styles. An informal observation we made was that there were three different design styles exhibited by the three different teams:

One team worked closely the entire session in order to achieve a consensus on the design decisions; one team worked independently on two parts of the design checking with each other only at the interaction of the two parts, and the third team established a leader who dictated the design decisions which were agreed to by the other designer.

Additional studies may lead to a better understanding of the different modes of collaboration.

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