VISUALISATION AND INFORMATION

Full Paper

MAPPING PLANNERS' INFORMATION-VISUALISATION REQUIREMENTS FOR 4D CAD DEVELOPMENTS

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ABSTRACT

This paper reports investigations into the needs and requirements of information visualisation for designers and building planners. The study firstly discusses current CAD visualisation approaches for planning. Current user preferences are established and measured from interviews with eleven construction professionals including planners, designers and contract managers. The resulting model predicts planners' requirements for information visualisation. The underpinning research method is that of Ethnographic research. The tools used allow qualitative attributes of data-display formats to be established. Interview transcriptions were coded and structured in grids containing 'hierarchy trees' and cluster 'diagrams' to identify relationships between participants and the topics of discussion. Planners' specific priorities and requirements for future software development are presented as principal components. The paper concludes with recommendations on two areas being firstly, directions for further developments in visualisation and secondly, implementation and consolidation of new planning tools.

Keywords: 4CAD, planning workbench, decision-making,

1. INTRODUCTION

This CRC Construction Innovation (CRC CI) "Contract Planning Workbench" project, on which this paper is based, is in Program C (Delivery and Management of Built Assets) of CRC CI. The main aim of the project is to demonstrate the feasibility of deriving draft construction schedules from IFC data generated from 3D CAD models. The project also investigates methodologies for automatically linking construction schedules with 3D CAD models to allow users to visualise and simulate construction schedules.

The project is a collaborative effort between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Manufacturing and Infrastructure Technology and the School of Architecture and Built Environment at the University of Newcastle (UN), together with two industry partners. CSIRO's contribution focuses on software development whereas UN's is that of providing underpinning knowledge, as well as data capture and analysis.

The first industry partner, Company *x*, is an Australian design consultant, founded over 100 years ago. This organisation has grown into an international design practice with 12 offices worldwide and over 300 staff. The company specialises in the design of facilities for health, education, transport, retail, residential, hospitality, sport and leisure, defence and commercial clients in the private and public sectors.

The second industry partner, Company *y*, is an international construction contractor founded over 50 years ago. It is a diversified contractor and a provider of operations and maintenance services to the rail, telecommunications, building and heavy engineering sectors.

This paper investigates the use and implementation of 4D CAD software and the working practices of our industry partners. 4D CAD refers to the dimension of 'time' added to more traditional bi- (2D) and tri-dimensional (3D) building and construction representation techniques. The paper adopts a qualitative research approach and provides insights into the views of individual professionals from the consulting and contracting sectors. Results identify current needs and expectations for visual aspects of planning.

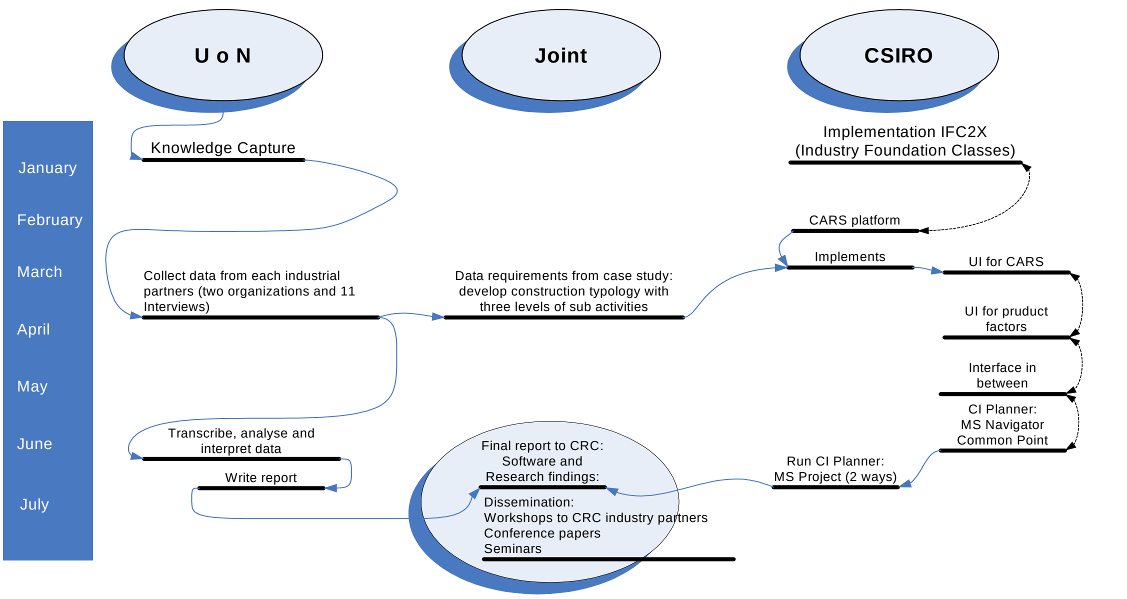


Figure 1 R&D workflow: construction planning workbench (CPW)

Figure 1 illustrates workflow and collaboration between the two research institutions. This paper focuses on UN activities and reports our findings. A description of the work of CSIRO is provided elsewhere in these conference proceedings. This paper reviews and investigates current 4D applications in the construction industry. It takes a pragmatic approach and identifies key factors which contribute to the commercial success of 4D systems in the Architecture, Engineering and Construction industries (AEC).

2. VISUALISING THE TIME DIMENSION

Planning is defined by Uher (2004 p.9) *as "a disciplined effort to produce fundamental decisions and actions that shape and guide what an organisation is, what it does, and why it does it".* This definition includes organisations with a limited time span, such as project-based organisations.

4D visualization techniques allow users to observe construction sequences in 3D environments. The logic of these sequences is based on conventional construction programming techniques such as Gantt charts and critical path analysis. The AEC industry is expected to derive real benefit from visualizing construction processes in a timeline (Rodgers, 2002 and Issa et al. 2003). Planning occurs at all stages of the design and construction process but emphases differ from stage to stage. At the highest level 'strategic planning' determines an overall project strategy. In later stages, 'operational' and 'coordinative' planning activities occur.

Hassan (1996) found that the application of such tools improved the management of processes on confined construction sites and facilitated precise co-ordination of activities. These results provide a strong incentive to use such systems.

- Schedule creation: 4D models help visualize schedule constraints and opportunities for schedule improvements through re-sequencing of activities or reallocation of workspace.
- Schedule analysis: 4D models help analyse schedules and visualize conflicts that are not apparent in Gantt charts and CPM diagrams.
- Communication: Many participants join projects midstream, and it is critical to induct new participants quickly. 4D models help facilitate such activities.
- Team building: A shared, visual model, capable of externalizing and sharing project issues is believed to be a valuable team-building tool.

In using 4D modelling for design Wong, (1997), and Schwegler, (1999) found that the technologies:

- Increase and improve information available for early project decision-making through pre-visualization or "3D sketching"
- Plan site and space use better
- Improve design quality
- Speed up evaluation of design
- Reduce time needed to model alternatives
- Improve co-ordination between design disciplines
- Share real-time work around the world

- Reduce design production work as fewer construction documents are needed

Designers can control the generation of information and this allows them to reap these benefits. According to (Schwegler, 1999) other benefits may accrue, such as reduced re-work, more productive field crews, and less wasted materials. In essence, these systems benefit all areas that require co-ordination, team-building and communication across current organizational and project phase boundaries.

Regarding added benefits, Fischer (2000) argued that 3D CAD should be a preferred way to document a design rather than an extra task to complete at a client's request. Several design / build firms reported that they were able to eliminate traditional 2D construction documents because these were produced directly from 3D models.

According to (Haymaker, 2001) other benefits of 4D CAD include:

- Planning to shorten construction period
- Improved evaluation of schedules
- Improved constructability and site constraints
- Avoidance of interferences on site
- Increased site safety
- Shortening site layout / surveying time
- Improved site layout accuracy
- Improved learning and feedback from project to project
- Improved effectiveness of communication.

Heesom et. al. (2004) found that 4D CAD models have proven to be particularly helpful in projects that involve many stakeholders, in projects undergoing renovation during operation such as hospitals, and in projects with tight, urban site conditions. Schewegler et.al. (1999) discussed the advantages of 4D modelling for design and construction and concluded that, by explicitly modelling the relationships between design, cost and schedule information, designers, planners and managers could automatically disseminate design and planning changes, whilst ensuring that a project's design, cost estimate, and construction schedule remained aligned.

Tarandi (2003) noted some advantages of 4D models produced by object oriented databases (e.g. Industry Foundation Classes). These included data originating from CAD models, such as bill of quantities, spaces, time and costs. These observations highlight data constructors may wish to exchange, in addition to drawings and 3D models. Tarandi concludes that exchanges are needed, not only between applications of the same type, e.g. CAD to CAD, but also between heterogeneous applications like CAD and cost estimation. Some examples of these desirable exchanges are (Tarandi, 2003):

- Building elements between two different CAD systems in one project
- Building elements from a CAD system to an analysis tool e.g. for structural analysis
- Bills of quantities from a CAD system to a cost estimation application
- Products / articles from catalogues / databases into CAD systems.

The following section introduces and discusses various commercial CAD and modeling products, emphasising visualization of timelines.

Haymaker (2000) concluded that the main contribution of using a 4D prototype tool included assistance in co-ordinating the activities of subcontractors, studying the construction of design, and verifying the executability of construction schedules.

Yerrapathruni (2003) reported case studies that use virtual immersive environments for design and programming various industrial facilities. For example, Cave™ (Automatic Virtual Environment) is a projection room with advanced visualization that combines high-resolution, stereoscopic projection and 3-D computer graphics to create the illusion of a complete sense of presence in a virtual environment for multiple users.

2.1 MIXED REALITY

Other areas of design and visualization now include the representation of objects in real space (Dias 2003; Salles, 2003). This means that elements of virtual environments are brought to real settings such as during face-to-face meetings. Dias (2003) reported current scientific developments in this field and argued that the breakthrough presented by ***augmented representations*** is *"the ability to interact with other people as visualising the model at the centre of the conversation".*

Mixed Reality (MR) is formally defined by Milgram et al. (1994, 1999) as a special class of Virtual Reality (VR) related technologies for creating environments where real world and virtual world objects are presented together in a single display.

An example of a current project using mixed reality technologies is ARTHUR™ (Romell 2001). ARTHUR is an acronym for "augmented round table for architecture and urban planning". The aim of this project is to bring elements of VR to traditional ways of practicing design and architecture. In addition, real-life, industrial experiments are currently being undertaken by well known practices such as Foster and Partners Architects (Foster and Partners, 2004; and Linie 4 Architekten, 2004).

Such technologies provide cohesive team-building opportunities as they facilitate interaction between participants during the briefing and programming stage. They are currently seen as a significant breakthrough in promoting collaboration and teambuilding (Wythe, 2004). According Dias-Salles (2003) these human-computer interfaces provide new and exciting opportunities to improve the way construction projects are planned, constructed and concluded. Although technology-related limitations have prevented these MR systems from maturing beyond the prototype stage, rapid technological improvements and capabilities are likely to make these feasible (Dias, M.J.S., et.al., 2003).

Figure 2 Mixed Reality Systems

Integrating MR with time enables different specialised integration. Heesom (2004) found that a valuable contribution of the 4D modelling process is that the process makes it very clear where complete scope and schedule information exists and where additional thinking is needed. Such systems provide highly collaborative multi-user environments and users are linked to mobile users by means of wireless networking Hessom, 2004). The latter are equipped with electronic agendas and wearable systems. Mixed Reality systems provide a new, highly innovative medium for design and planning.

3. FIELD STUDY: MAPPING PLANERS' INFORMATION VISUALIZATION REQUIREMENTS

This section describes investigations to elicit the views of experienced practitioners about their needs and expectations in reading and interpreting planning data. The study adopted a qualitative and consultative approach, using semi-structured interviews with 11 key design and construction professionals. These individuals held different roles within their organisations, and had different levels of experience. The two participating companies from which interviewees were recruited have been described in Section 1.

3.1 QUALITATIVE DATA ANALYSIS

Research approach and method

The interview methodology and procedures reported here were approved by the University of Newcastle, Human Research Ethics Committee (Approval No. H-767-0204).

The study assessed participants' responses to concepts of 4D CAD and information display and representation. Fieldwork was undertaken with planning professionals from partner organizations, and results were documented and compared across individuals and organisations. The approach underpinning the study is that of Qualitative Data Analysis (QDA) (Seidel, J., 1998).

QDA provides insights into theoretical and applied studies of knowledge, perception and cognition (Denicolo and Pope, 2001). Attitudes can be discerned in qualitative studies and these can be measured using a variety of methods. The approaches adopted for this study, called Ethnography (Seidel, 1998) and Repertory Grid analysis (Kelly, 1955; Stewart, 1980), were used to structure and synthesise data for all interviews.

The interview analysis software used includes: Ethnograph® (2000) and GridSuite® (Fromm, 2003) and Adobe Acrobat Professional™ (2004). These packages assisted content analysis and interpretation. They provide useful facilities for interpretative studies, including data coding, structuring and sorting.

Figure 3 Model for interview analysis (Seidel, 1998) describes the *iterative* process of data analysis and interpretation adopted. The first step involved importing and numbering files, followed by coding, searching for segments, and finally identifying new aspects before repeating the process again. The model also shows the software used during the various investigative steps. Aspects of the analytical process and the use of content analysis software follow.

Ethnograph® was used for content analysis and to code text files. Once interviews were transcribed, various emergent themes were identified. Figure 4, which shows some of these themes, is the result of iterative topics of discussion across participants (and records common issues that were noted by all interviewees).

The initial text, coded in Ethnograph, was then imported into Adobe Acrobat Professional™ for *reiterative* cluster identification. The impact of this was that themes were searched for and reviewed using different but similar software. This added *rigour* to the search for segments and assisted in identifying unique aspects. Some advantages of this dual software approach include:

- They are user friendly - especially in the coding of text segments and procedures
- They facilitate the assignment of author, participant, theme and topic
- They provide text highlighter, symbol and colour coding facilities
- They contain search facilities (by key words or key segments, as hypertext relationships)
- They contain facilities to sort codes in a number of ways (such as by theme, author, date, participant, colour and so forth)
- They are able to export relational summaries and reports

At the discovery stage (see Figure 3), cluster themes were identified and derived for the text samples transcribed. Nodes and keywords were then arranged and sorted in clusters and relational tables. Tables in this study were created using GridSuite© (Fromm, 2004). This software assists in summarising and presenting qualitative data. This is made possible by assigning all key themes and words across all respondents. It is then possible to generate a *repertory grid* for each participant. After individual coding all repertory grids were merged, creating a single relational grid of all interviews. The repertory grid thus presents an overview of entire interviews, and includes all participants and their themes. These grids were then scrutinised and interpreted.

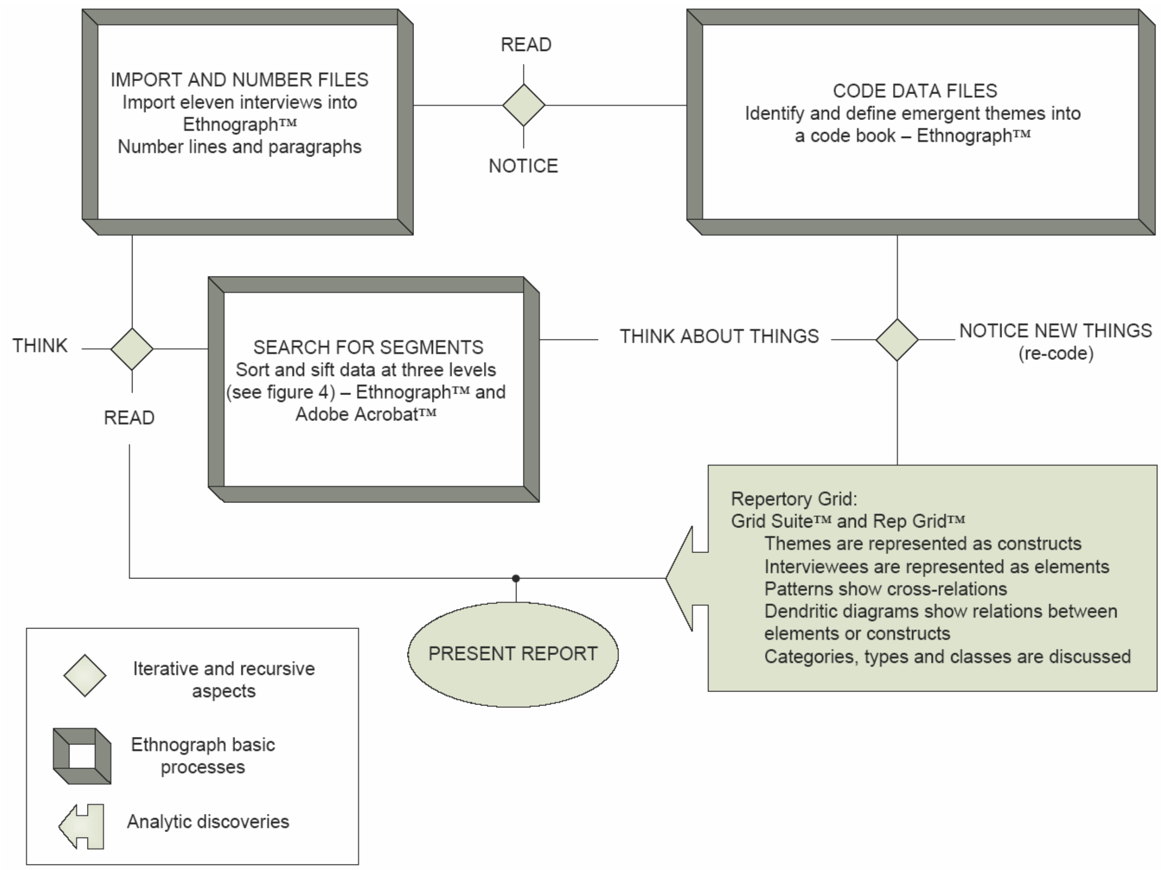


Figure 3 Model for interview analysis (Seidel, 1998)

Interview structure

Interviews were structured in the following six main sections:

- General questions (e.g. participants' position and profession)
- Background information (e.g. experience)
- Case study information
- Programming specific questions
- Information visualization (e.g. data display formats)
- Strategies for Company IT development

Interviews were recorded using digital mini-disks and transcribed in MS Word™. Speech segments were identified and tracks marked to facilitate transcription. Once transcriptions were saved, access to data was restricted to the chief and co-investigators. Recordings were then destroyed and transcripts rendered anonymous.

Transcribed data were imported into Ethnograph™ (Siedel,1998) to facilitate content analysis. A data file containing relational information from the interviews (e.g. common keywords and similar concepts) was named 'the code book' (see Figure 4). The code book also summarises segments identified from the initial interview schedule (level 2 in Figure 4) and key words were then assigned to textual segments (level 3 in Figure 4). Once all transcriptions were coded, comparative sorting occurred. It was then possible to identify a series of "common underlying" themes.

In the context of this study, "themes" represent issues of concern voiced by the interviewees. The activities that identified these themes are shown in are Figure 4. Developing a code book and searching for segments is an iterative process and for this study the first level of the code book was structured as the original interview schedule. An initial search identified relationships between the full interview transcript and the interview schedule (shown at level one). This activity was important because questions were not answered in the same order as the interview schedule. Level 2 refers to the themes identified as main (or cluster) themes. Cluster themes represent key areas of concern as viewed by the interviewees and contain twelve themes and six clusters. Level 3 identifies differing attributes that relate to individual views. It aims to provide a framework to compare and contrast interviewees and their views.

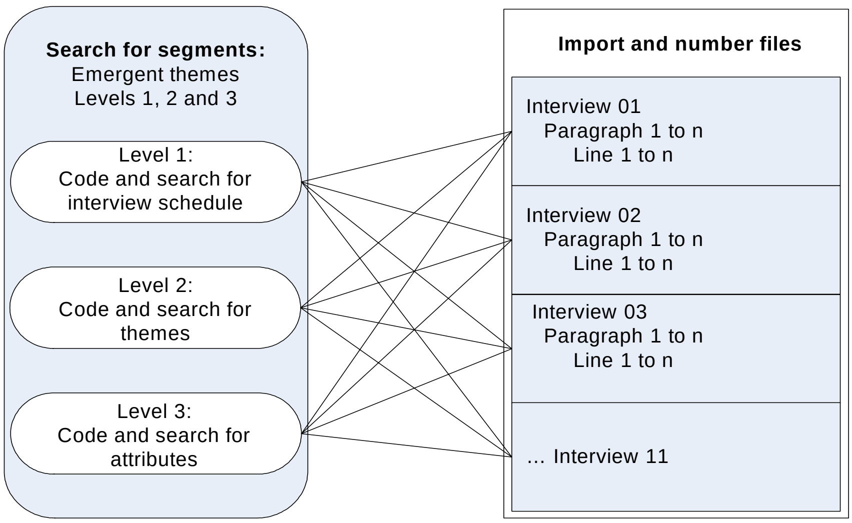


Figure 4 Code book and search for themes

In structuring interview data, all themes were derived from records of discussions. As part of content interpretation, opposites (or *bipolar*) attributes were assigned to participants' responses. These opposites relate to one side of the pole rather than the other.

Content analysis

The initial common themes in the interview data where synthesised into six main 'clusters'. They were then coded and highlighted to assist content analysis. Emergent themes at level two were summarised in *six clusters*, categorised as: *Personal, Case study Visualisation, Innovation, Barriers* and *Benefits*.

All transcribed interviews were coded in Adobe Acrobat Professional™ (2004). Codes were then assigned colours, and colours were also allocated to individual interviewees, researcher's comments and data. Content in the overall interview text refers to any of the six cluster themes which were identified and underlined, as shown in Figure 5.

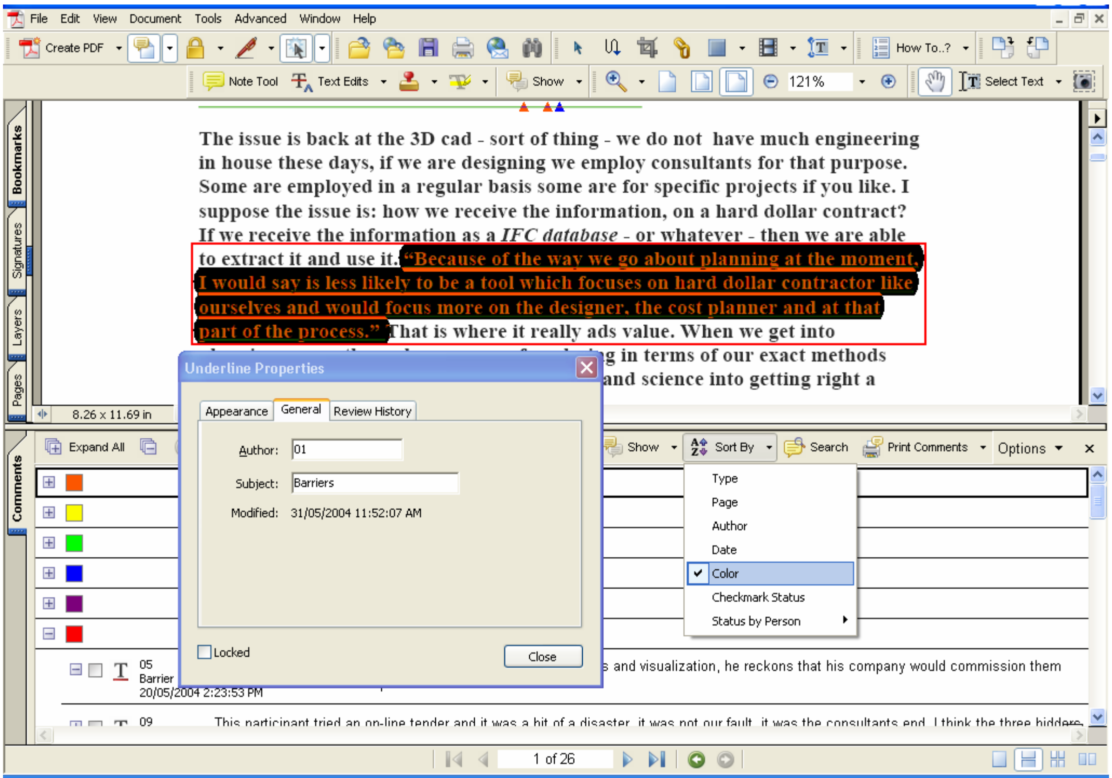


Figure 5 Coding and searching for segments

The interview schedule was structured as follows:

- Background information
- Case study information
- Programming specific questions
- Information visualization
- Data display formats
- Strategies of Company IT development

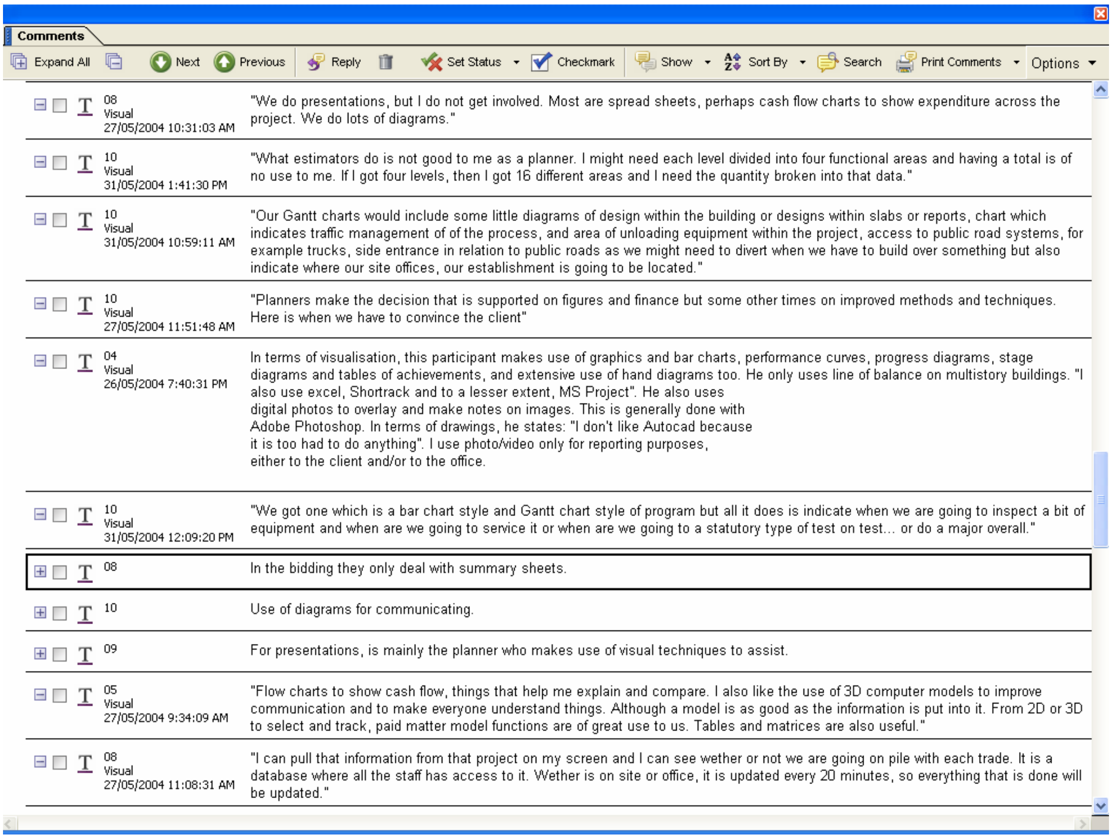


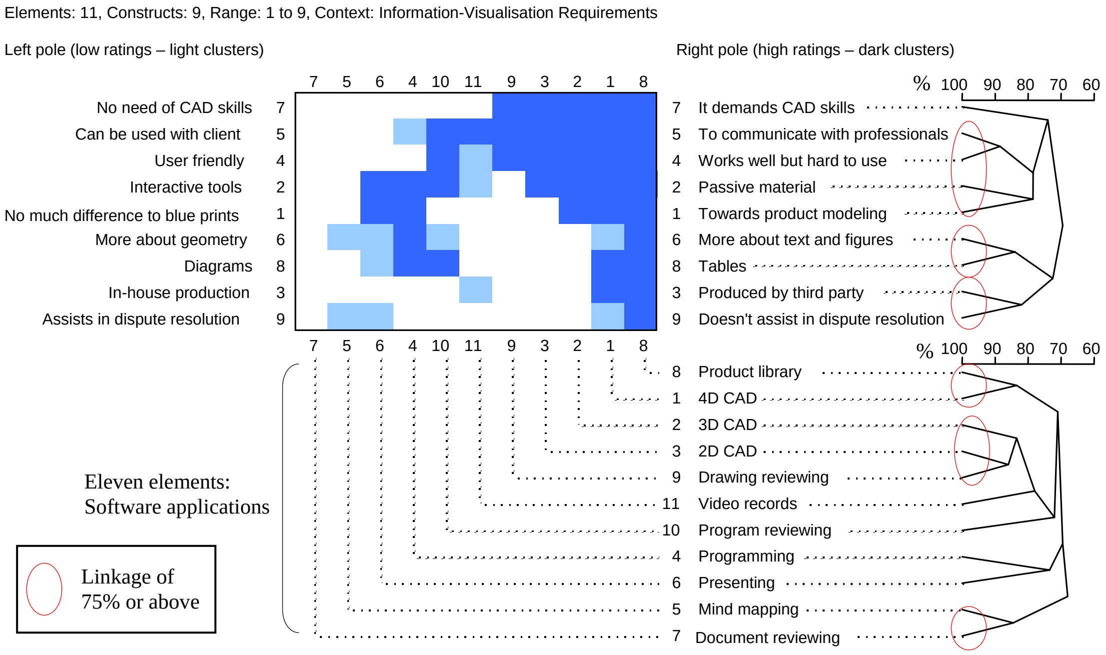
Figure 6 Cross analysis of 5 interviewees

3.3 ANALYSIS OF RESULTS

Structuring interview data in Repertory Grids has been discussed in detail by Denicolo and Pope (2001), Slater (1977) and Kelly (1955). In this study all interviews were coded as repertory grids using RepGrid™.

Figure 7 is a relational table of software and attributes as viewed by the participants. Eleven elements represent the various tools and technologies for visualisation. The columns at each side of the table represent the attributes of the constructs.

Figure 7 Attributes Gird



The Repertory grid diagram shown in Figure 7 provides a cross comparison of individuals' views about visualisation tools and technologies. It is in the form of a matrix containing elements (software tools) and constructs (identified attributes) themes (or topics under discussion) presented.

For the study 11 participants were interviewed about the use of visual aids in design and construction. The study focussed on the use and implementation of 4D modellers and information visualization techniques.

- Element 1: **4D CAD** - refers to the time dimension added to 2D and 3D CAD drawings or models. Software reviewed includes Archicad™ v7 and Commonpoint™.
- Element 2: **3D CAD** - refers to design tools such as Archicad where design is three-dimensional.
- Element 3: **2D CAD** - refers to the more traditional CAD procedures.
- Element 4: **Programming** - refers to software for planning and scheduling such as Primavera P3™, MS Project™ and others.
- Element 5: **Mind mapping** - refers to tools and software to map such as Mind Manager™.
- Element 6: **Presenting** - refers to the use of tools such as MS Powerpoint™, Adobe Photoshop™ and on the high end Macromedia™ tools.
- Element 7: **Document review** - refers to tools and software packages such as Adobe Acrobat™.
- Element 8: **Product library** - refers to 'database libraries' such as IFC's and STEP.
- Element 9: **Drawing and reviewing** - refers to software packages such as Autodesk Autocad™ and Archicad™.

- Element 10: **Program reviewing** - refers to software tools such as reviewing facilities within Common Point™ or similar programmes.

- Element 11: **Video and photo records** – refers to digital or analogue.

The relationship between the elements involved calculating correlations between the various current and expected visualization techniques, such a 3D CAD display.

Since common elements correspond to semantic differential concepts, common constructs correspond to semantic differential scales, the data analytic problem being equivalent (Bannister 1968). However in semantic differential analyses, attention is generally focussed on either concepts or scales, and is the equivalent of the important relationship of element construct interactions. A way such data can be analysed is through three-mode principal components (Bell 1999) (see Figure 7).

Figure 8 shows that the items were plotted sequentially in a radial pattern, suggesting a qualitative sequence. The variance and coefficient of alienation in the three-dimensional solution was 20, which presents a degree of distortion on the plot. However, the basic configuration suggests a number of patterns, in that four groups of elements (such as 'software tools') are readily identifiable. To aid interpretation, elements related to the regions are coloured differently, indicating the relational calculations for the principal components.

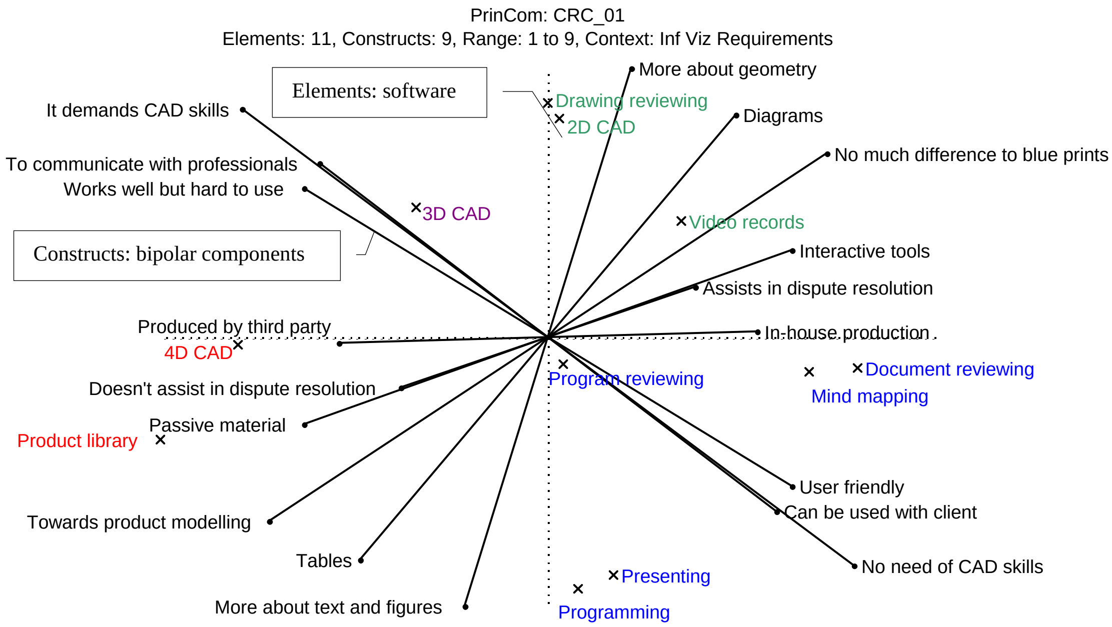


Figure 8 Principal Components: attributes

Figure 7 refers to the arrangement of 9 bipolar constructs and 11 elements. It defines how the elements relate to the constructs. Quadrant top-left 3D CAD and 'programming' relates closely to attributes such as 'works well but hard to use', 'to communicate with professionals', and 'it demands CAD skills'. In the opposite quadrant, (bottom-right), software packages for reviewing (e.g. Adobe Acrobat™) and presenting (such as MS Power Point™) would closely relate to 'user friendly', 'can be used with the client' and 'no need of CAD skills'. '4D CAD' and 'Product Library' are in the lower-left quadrant and relate to the attributes on that side.

Result variation is part of the process of comparing current and future views of visualization requirements. Constructs and elements have been sorted so that those that are more similar in the two grids (present grid and future grid) are the top and on the right, respectably. For example element (7) 'document reviewing' tools and procedures are expected to change considerably.

CRC_01+ consensus-with CRC_01. Expected future for information-visualization: darker clusters refer to stronger change expectations (lower left corner).

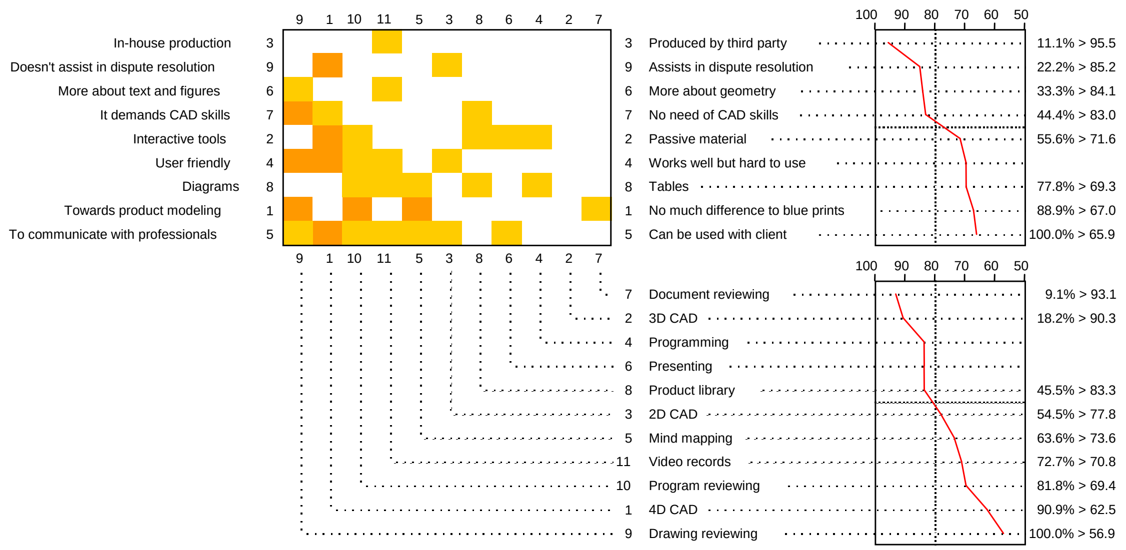


Figure 9 Validation grid

Software for document reviewing (E7), visual aspects of 3D CAD (E2) and programming tools (E4) are expected to function and perform as they currently do. Other tools / elements such as drawing reviewing (E9), 4D CAD (E1) and program reviewing (10) are expected to change and improve the way they currently perform. Architects and planners need more user-friendly project reviewing tools to facilitate interactions with clients. Current tools and approaches are more likely to hinder communication.

The largest change and expectation remains the development of tools 'to communicate with professionals' especially 9, 1, 10, 11, 5, 3 and 6.

All procedures have their limitations. For example Patrick Slater (1976) debated the merits of principal components analysis vs. cluster analysis. Mair (1988) wrote about the problems of correlational approaches, and there has been debate about the different distance measures which are used in cluster and other analyses. These issues need critical consideration in determining how data is to be analysed, especially when comparing multiple participants' responses.

This section has detailed future needs and expectations of planning and visualisation software.

4. Software assessment and future development

Creating a 4D model is generally perceived as highly challenging and labour intensive. Issues confronting users relate to geometry, schedule, and the linking of geometry to schedule.

The model used in this project to interface and communicate 4D CAD is based on Industry Foundation Classes, and was found to perform well. It provided an effective tool to integrate CAD models and planning software but has not been refined to a commercial standard as yet. There is a need to develop an interface for practitioners and a 'light' viewing interface for reviewing and use by non-professionals.

Another reason for these issues is that the construction of a 4D model requires significant project scope and schedule information. Some of this information is precisely the information that project participants want to develop or refine through the 4D modelling process.

The results also revealed the need for "user friendly tools" that can assist at the briefing process.

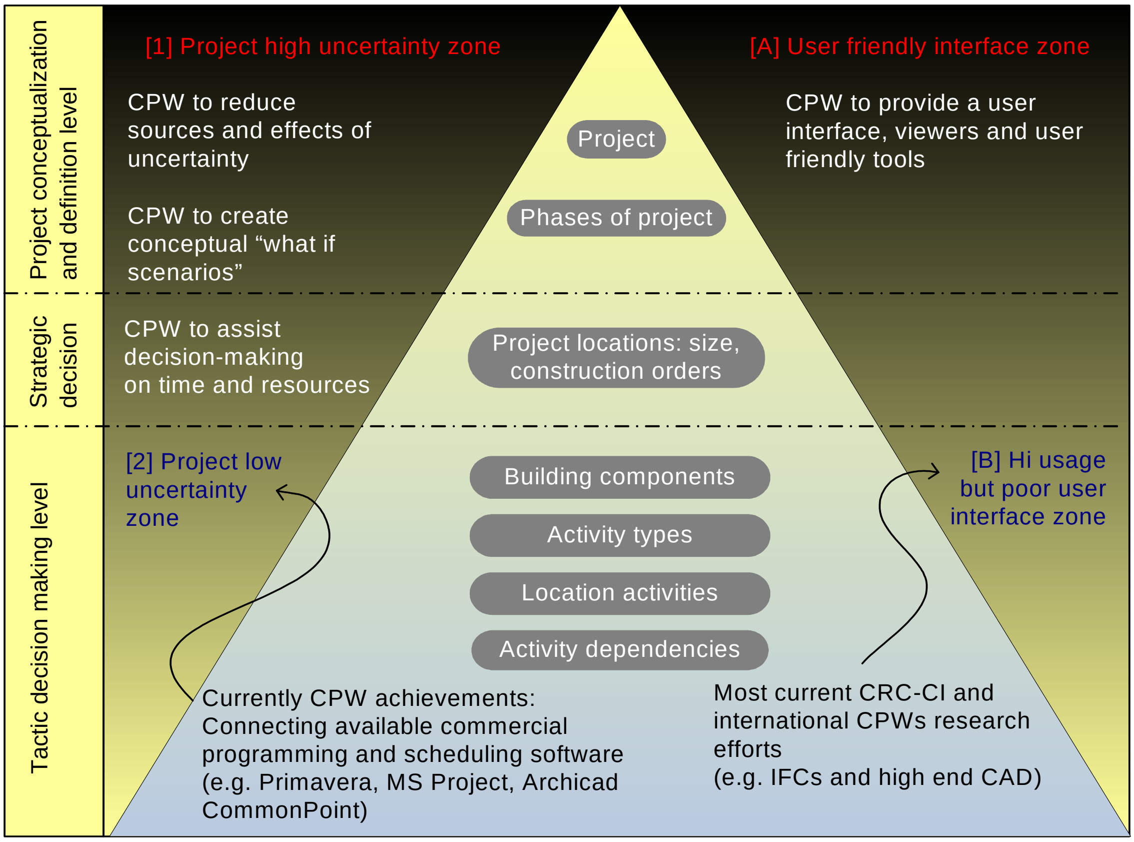


Figure 10 Construction Planning Workbench (CPW) current and future developments

Is CPW satisfying current needs and expectations from industry partners? For CPW to perform well, a second stage is needed to provide a user interface for planners, designers and construction professionals. Figure 10 illustrates current achievements and future directions for CPW.

Currently 4D models are generated by a combination of planners and 3D experts.

Future efforts should also investigate the interface provided by 4D modellers, with a minimum of technical support. Relevant comments by interviewees include:

> "With the use of 4D CAD, the relationship between client and designer will improve."

> "With the use of 4D CAD the relationship between contractors, subcontractors and suppliers will improve."

4D simulation may also be used to plan site logistics and space usage on construction sites, processes that frequently have conflicting requirements. Another area where 4D would be of value includes detecting potential time-space conflicts that may occur between activities being executed on a construction site.

In summary, 4D CAD provides tools which integrate theoretical frameworks to predict engineering behaviour. This allows for projects to be systematically managed using predictions and observed data to achieve measurable business objectives.

Discussion: Visualisation in dispute resolution

Dispute resolution is an area where 4D technology could be developed and applied. Take for example, a typical claim for an extension of time. To effectively prove an entitlement to an extension of time, a claimant needs to:

- Establish that the contract allows an extension of time for the delaying event in question;
- Comply with the procedural requirements of the contract with regard to notices and notification of the party's intention to make a claim;
- Prove that the claimed event was the cause of the delay;
- Quantify the period of delay; and
- If the contract allows, establish and quantify the costs of the damages suffered as a result of the delaying event for the period of the delay.

The provisions of the contracts determine if a party is entitled to make a claim under the contract and outline the notification procedures and time in which the relevant notices must be given. Establishing that the delay was the result of a specific event or events on large complex projects can be difficult and argumentative. Agreement of the actual events that took place has to be reached prior to determining the effects of those events on the project programme. Determining the effects typically involves the calculation of the amount of time the project has been delayed by way of a critical path analysis, comparing the original 'as planned' project duration with the resultant 'as built' project duration. The difference between the durations is perceived to be the effects of the delaying events and is estimated to be the period of the extension of time. This process is not without argument in itself. A number of delay analysis techniques are recognised as being suitable for this purpose, such as the global impact, net impact, adjusted as built, "but for" or collapsing, snapshot, and time impact techniques (Pickavance, 2000, Alkass et al, 1996, Wickwire et al, 1991, Reams, 1990, Leary and Bramble, 1988). These provide a means of "accurately" quantifying the time element of the analysis, all requiring agreement as to which method of analysis should be used, which computer software should be applied, and which project programme should be analysed. These issues should be addressed prior to the commencement of the project, but even where this is done, the person determining the period of the extension of time requires detailed knowledge of programming and analysis procedures to ensure meaningful results.

Provided the logic of the 'planned' programme and 'as built' programme are accepted as being correct, and agreement has been reached concerning the delaying events in question, the use of nD modelling would enable a pictorial representation of the 'as built' project to be constructed in real time for comparison with a pictorial representation of the 'as planned' project constructed in real time. The visual aid would enable a non-expert to see the effects of the delaying events by comparing the 'as planned' and 'as built' models over time. This would assist in determining the consequences and true effects of the agreed delaying events without the need for detailed knowledge of programming and analysis techniques by the person responsible for determining the period of extension. Visibly seeing the effects of the delaying events would help in resolving the issues in conflict and would enable agreement to be reached concerning the period of extension.

5. CONCLUSION

Planners and construction professionals are increasingly finding real value and benefit from the use of 4D technologies. The CRC CI funded 'Construction Planning Workbench' project has shown that IFC's provide an effective vehicle to facilitate the provision of draft construction programs directly from CAD data. However, issues of who should be responsible for developing and maintaining 4D and IFC data remain to be overcome.

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