ARTICLE

Evolving Trends in nD Modelling: The ‘Construction Planning Workbench’

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Abstract

This paper investigates the requirements of product modelling in the construction industry. Product models incorporate multifaceted aspects of design information (required at each stage of the lifecycle of buildings) by integrating additional information (such as time, costs, etc.) into a three-dimensional (3D) computer model, thereby adding intelligence to it. The project also investigates methodologies for automatically linking construction programs [Q1] with 3D CAD models to allow users to visualize and simulate construction methodologies. Our study adopts a qualitative approach where semi-structured interviews were conducted with 11 key design and construction professionals from two major Australian companies. Data were coded in relation to six main clusters – themes and summaries of results are presented as repertory grids. The paper identifies some of the risks and opportunities of implementing nD modelling in the construction industry. Analysis of data indicates a shift to 3D CAD, with a strong interest being identified for integration of CAD and construction programming. Although the use of product models is not presently seen as feasible for this purpose, the increasing use of 3D CAD is seen as positive. Results indicate a need for alignment models and user-friendly technologies if product models are to assist communication between clients, consultants and construction companies.

Keywords – Industry foundation classes; nD modelling; product modelling; qualitative data analysis

INTRODUCTION

The Cooperative Research Centre for Construction Innovation (CRC CI) (at http://www.construction-innovation.info/) is a national research, development and implementation organization focused on the needs of the property, design, construction and facility management sectors of the Australian economy. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government’s ‘Cooperative Research Program’, the CRC CI is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. The CRC CI is funded by a Commonwealth grant as well as industry, research and other government support for seven years. More than 150 researchers and an alliance of 19 leading partner organizations are involved in and support the activities of the CRC CI, which comprises three research areas:

- Programme A – Business and Industry Development
- Programme B – Sustainable Built Assets
- Programme C – Delivery and Management of Built Assets.

Underpinning these programmes is an Information Communication Technology (ICT) platform.

The ‘Construction Planning Workbench’ project (the CRC CI project described in this paper) is in Programme C. The main aim of the project is to demonstrate the feasibility of deriving draft construction programs [Q1] from Industry Foundation Class (IFC) data generated from 3D CAD models. The project also investigates methodologies for automatically linking construction programs [Q1] with 3D CAD models to allow users to visualize and simulate construction methodologies.
The project is a collaborative effort between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Manufacturing and Infrastructure Technology division and the School of Architecture and Built Environment at the University of Newcastle (UN), together with two industry partners. CSIRO has developed the software tools, while UN has reviewed literature and conducted interviews and focus groups. The first industry partner is an Australian design consultant, founded more than 100 years ago. This organization has grown into an international design practice with 12 offices worldwide and over 300 staff. The company specializes 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 is an international construction contractor founded more than 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 addresses the challenges of developing and implementing computer tools that harness IFC data to automatically produce construction programs [Q1]. It describes qualitative research conducted by UN into the needs and expectations of four-dimensional (4D) CAD systems (where the fourth dimension is 'time') and the use of IFCs. In addition to a brief review of relevant concepts, it provides insights into the views of companies and individual professionals from the consulting and contracting sectors of the construction industry.

BACKGROUND TO PRODUCT MODELLING

The use of 'product models' represents a significant progression in the way graphical information is visualized. Since the end of the 1990s, most leading CAD developers have shifted from two-dimensional (2D) CAD to three-dimensional (3D) CAD and object-based systems. Unlike the 2D CAD approach, where building components are created from lines and arcs, 3D (and nD variant) designs are executed in three-dimensions from their inception [Finch, 2003][Q2]. In nD environments, standardized building components are increasingly designed as objects and stored in online shared repositories. Some objects also embed additional information such as costs, safety codes, connectivity, strength, lifecycle data and other relevant data.

![FIGURE 1 IFC product modelling](image-url)
attributes. The resulting models become detailed representations that may be displayed in many different ways (for example, as 3D models, spreadsheets, drawings, tables, etc.) to meet the information requirements of architects, engineers and constructors (Fischer and Kam, 2000).

The effectiveness of nD modelling relies on the interrelationships between 3D objects. By forming such relationships, designers can explore the manner in which the objects behave collectively. Much of the information required to inform decisions (about, for example, construction sequence, thermal performance and so on) can be stored in these objects. By testing these models, designers may explore alternatives (such as multiple case studies, ‘what-if’ scenarios and so on) to refine their designs or to enhance buildability (Heesom, 2004).

Standards have and are emerging to govern nD models. These include Industry Foundation Classes (IFC) and the Standard for the Exchange of Product Model Data (STEP). IFC is a data protocol that seeks to create a common international ‘object library repository’. Figure 1 shows a building model composed of IFC objects that have been harvested from an IFC ‘model server’. STEP is similar, being an International Organization for Standardization (ISO) standard that arose out of collaboration between several industries, and was developed to facilitate consistency of use. Both IFC and STEP provide a standard for exchanging product model data. They also prescribe protocols for information requirements, allowing specific activities to be performed (Kim, 2004).

In our research, IFCs have been used to catalogue various building objects within a case-study project. Software tools have been developed to automatically combine the construction/placement of these objects into construction activities, which are then automatically sequenced. The tool provides a first-cut construction program which can be imported into ‘off-the-shelf’ project management software (e.g. Primavera™, MS Project™) for further analysis. Figure 2 provides a diagrammatic representation of the manner in which

![Diagram of data flow in product modelling](image-url)
The sequencing information may also be imported into ‘off-the-shelf’ 4D CAD systems (i.e. 3D CAD sequenced over time) such as Bentley Navigator™, Archicad™ and Common Point™ to allow users to review digital construction sequences. With 4D CAD, information about the objects in a building is available at the end of the detailed design process through the IFC data. The information about classes of building objects can then be combined to schedule activities, as noted by Fischer and Kam (2000).

Kiviniemi (2002) suggests that product modelling in the construction industry will be facilitated by the Internet. Finch (2000: 48) states that:

*With the advent of the Internet as a design medium, it is no longer a matter of passing a single design concept through a linear process of steps, all neatly articulated in discrete domains of expertise... the potential of implementing these technologies provides a new way of working in architectural and engineering design.*

This means that design and construction processes have the potential to be fully integrated. Such integration is significant as it will enable several design professionals to engage simultaneously in design processes. This will fundamentally challenge our existing models of design.

The IFC protocol closely relates to the concept of product modelling, where building components drawn on a CAD system are understood as 3D objects with ‘n’ properties (Katranuschkov et al., 2003). Thus, if a wall is drawn on a building layout, the wall is understood as a volume composed of other volumes. Figure 1 illustrates some of the dimensions added to traditional 2D and/or 3D drawings to create a ‘product model’ containing cost, schedule, space and accessibility information. This model can then be modified and/or explored to evaluate outcomes and to assist in making decisions.

Human factors are paramount when evaluating outcomes, making decisions and using object models because new tools (such as those described in this paper) involve changes to contemporary ways of working (Dias et al., 2003). Human factors (for example, ergonomics and the manner in which these tools align with traditional practices) need to be considered and catered for if innovative tools and new working approaches are to be used effectively (Andersen, 2000). Fairuz (2003) and Marshall-Ponting (2004) agree that those using product models (for example, architects, engineers, construction contractors and clients) need to engage in organizational training and education throughout the design process. Andersen (2000) also recognizes the need to intensively train and familiarize clients, professional designers and construction personnel with new systems and ways of working. Stewart (2000) argues that training is the most cost-effective way of changing attitudes in the highly conservative construction industry.

In this context, it is informative to note Whyte’s (2001) observations of the short-comings of virtual reality (VR) and product modelling. She identifies the complexity of these systems and their reliance on highly qualified operators as factors likely to challenge those wishing to implement them. Her views align with those of Fischer and Kam (2000: 37) and Heesom (2004) who note such challenges when product modelling was used with clients and non-CAD specialists. In addition, Terrance et al., (2001) found that, to improve the uptake of nD and product modelling technologies, collaboration between the architecture, engineering and construction (AEC) industry, clients, technology providers and researchers was very important.

This section has briefly described the concepts and use of object models. It has explained the potential these systems have to influence and change the manner in which buildings are designed, and has alluded to the sequence of construction activities inherent in such designs. The next section describes interviews with our industry partners. These were conducted by UN, and highlight key areas that informed developments of the software tools described in this paper.

**ELICITING THE VIEWS OF OUR INDUSTRY PARTNERS**

Semi-structured interviews were conducted with 11 key design and construction professionals employed by our industry partners. The study was qualitative and we sought to establish interviewees’ attitudes about product models. The people interviewed occupied various roles within their organizations and had different levels of technical experience.
RESEARCH METHOD
The study assessed participants’ responses to concepts of 4D CAD, nD and product modelling. The interviews were conducted and audio recorded at the offices of our industry partners. The recordings were transcribed and the resulting data analysed and compared across individuals and organizations. The approach underpinning the study is that of Qualitative Data Analysis (QDA) (Seidel, 1988). QDA provides insights into theoretical and applied studies of knowledge, perception and cognition (Denicolo and Pope, 2001). In such studies, attitudes can be discerned 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 synthesize data for all interviews. Our interview methodology and procedures were approved by the University of Newcastle, Human Research Ethics Committee (Approval No. H-767-0204).

The interview analysis software used included Ethnograph® (Anon, 2000); GridSuite® (Fromm, 2004); and Adobe Acrobat Professional™ (Anon, 2004). We used these packages to assist with content analysis and interpretation as they provide useful facilities for coding, structuring and sorting data. Of particular interest are the ‘sorting’ facilities which allowed us to consider our data in several different ways (as described in Content Analysis).

Figure 3 shows the iterative process of data analysis and interpretation we adopted. The first step involved importing and numbering interview data files, followed by coding files, searching for segments, and finally identifying new aspects before repeating the process again. Figure 3 also shows the software used during the various investigative steps. Aspects of the analytical process and the use of content analysis software are described below.

FIGURE 3 Model for interview analysis (Seidel, 1998)
The Ethnograph® was used both for content analysis and to code text files. Once interviews were transcribed, various themes were identified. The transcribed text, coded in Ethnograph®, was then imported into Adobe Acrobat Professional™ for reiterative cluster identification, the impact of which was to search for and review themes using different but similar software. This added rigour to the search for segments and assisted in identifying unique aspects of the data. Some advantages of this dual use of software include:

- the packages are user friendly, especially for coding text segments and procedures
- they facilitate the assignment of meta data for authors, participants, themes and topics
- they provide text highlighter, symbol and colour coding facilities
- they facilitate searches (by key words or key segments, as hypertext relationships)
- they provide multiple sort facilities (such as by theme, author, date, participant, colour and so forth)
- they are able to export relational summaries and reports.

Cluster themes for the transcribed text samples were identified and noted (as shown in Figure 3). Nodes and keywords were then arranged and sorted in clusters and relational tables. Tables were created using GridSuite© (Fromm, 2004) and assisted us in summarizing and presenting qualitative data. All key themes and key words were assigned across all respondents, making it possible to generate a repertory grid for each participant. After coding, all repertory grids were merged, creating a single relational grid of all interviews (see Figure 8). This relational repertory grid thus presents an overview of all interviews, and includes all participants and their themes. The grids created for individual respondents were then scrutinized and interpreted.

INTERVIEWS
Interviews were structured into the following six main sections:

- general questions (e.g. participants’ position and profession)
- background information (e.g. experience)
- case study information
- scheduling/programming
- information visualization (e.g. data display formats)
- strategies for company IT development.

Interviews were recorded using a digital audio recorder and then transcribed into MS Word™. Speech segments were identified and tracks were marked to facilitate transcription. Once saved in a computer system, access to transcribed interview data was restricted to the chief and co-investigators. Recordings of interviews were then destroyed and the transcripts rendered anonymous. These practices for protecting the anonymity and confidentiality of interviewees are prescribed by our University ethics committee.

Transcribed data were then imported into Ethnograph™ (Siedel, 1998) to facilitate content analysis. A data file containing relational information extracted from the interviews (e.g. common keywords and similar concepts) was created (and named the ‘code book’ – see Figure 4). The code book also summarizes the segments identified from the initial interview schedule (level 2 in Figure 4) and keywords were then assigned to textual segments (represented in level 3 in Figure 4). Once all transcriptions had been coded, comparative sorting occurred and it was 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 process of identifying these themes is shown in 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 1 in Figure 4). This activity was important because questions were not always answered in the same order as the interview schedule. Level 2 (Figure 4) refers to the themes identified as main (or cluster) themes. Cluster themes represent the key areas of concern identified by the interviewees and contain 12 themes (T2 to T13 below) and six clusters (see Figure 5). Level 3 (Figure 4) identifies differing attributes that relate to individual views and provides a framework by which the views of interviewees may be compared and contrasted.
TABLE 1 Bipolar themes

<table>
<thead>
<tr>
<th>THEME</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D CAD (T2)</td>
<td>These themes relate to the software used by the interviewees</td>
</tr>
<tr>
<td>3D CAD building documentation (T3)</td>
<td>These themes were also noted by Whyte (2001: 101). She observed the use of VR for a range of tasks, and compared and contrasted interactions and communications between non-professionals and other AEC professionals.</td>
</tr>
<tr>
<td>Use of VR to assist communication with clients (T4)</td>
<td></td>
</tr>
<tr>
<td>Use of VR to assist communication with other professionals (T5)</td>
<td></td>
</tr>
<tr>
<td>Client driven innovation (T6)</td>
<td>These themes identify the parties viewed as promoting the use and adoption of innovative technologies</td>
</tr>
<tr>
<td>Industry driven innovation (T7)</td>
<td>These themes relate to the adoption of software, and to the tensions apparent between consultants and contractors. The latter saw themselves as close ‘followers’ of technology, and anticipated that data models would be created by third parties, or by consultants (T8). By way of contrast (T9) caters for situations where contractors create data models.</td>
</tr>
<tr>
<td>Developed by consultants (T8)</td>
<td></td>
</tr>
<tr>
<td>Developed in-house (T9)</td>
<td>The themes of ‘feasible to use now’ (T10) and ‘feasible to use later’ (T11) concern vision and timing, and refer to the scope of these aspects.</td>
</tr>
<tr>
<td>Feasible for use now (T10)</td>
<td>‘To be applied in many projects’ (T12) and ‘to be applied in a single project’ (T13) impact on multiple and single projects respectively. These views relate to whether implementation is effected throughout an organization, or by individual enthusiasts. Testing new software packages on real projects involves a certain degree of risk and industry partners had agreed to implement the system in small incremental steps.</td>
</tr>
<tr>
<td>Feasible for use later (T11)</td>
<td></td>
</tr>
<tr>
<td>To be applied in many projects (T12)</td>
<td></td>
</tr>
<tr>
<td>To be applied in a single project (T13)</td>
<td></td>
</tr>
</tbody>
</table>
In structuring interview data, all themes were derived from records of discussions. As part of content interpretation, opposites (or bipolar) themes were assigned to participants’ responses (see bipolar themes highlighted as pairs in Table 1). For example, some participants viewed the use of 3D CAD as a tool to improve communication with construction professionals, whereas others saw it as a medium to assist communication with clients.

**CONTENT ANALYSIS**
The themes identified in the interview data were synthesized into six main clusters (shown in Figure 5). They were then coded and highlighted to assist content analysis and emergent themes at level 2 (shown in Figure 4) were summarized in this manner. Clusters were categorized as: personal, visualization, case study, innovation, barriers and benefits (see Figure 5).

All transcribed interviews were coded in Adobe Acrobat Professional™ (2004) [Q4]. Colours were then assigned to codes, as well as to individual interviewees, researchers’ comments and data. Researchers’ comments and notes were added to the transcribed text, resulting in a 30-page document. Content in the overall interview text referring to any of the six cluster themes was identified and underlined, as shown in Figure 6, and presented for analysis, as shown in Figure 7. This text was then sorted in several different ways to facilitate further scrutiny and interpretation, including:

**FIGURE 5** Emergent clusters at level 2
The issue is back at the 3D cad - sort of thing - we do not have much engineering in house these days, if we are designing we employ consultants for that purpose. Some are employed in a regular basis some are for specific projects if you like. I suppose the issue is: how we receive the information, on a hard dollar contract? If we receive the information as a IFC database - or whatever - then we are able to extract it and use it. Because of the way we go about planning at the moment, I would say is less likely to be a tool which focuses on hard dollar contractor like ourselves and would focus more on the designer, the cost planner and at that part of the process. That is where it really adds value. When we get into terms of our exact methods and science into getting right a

FIGURE 6 Coding and searching for segments (from Adobe Acrobat Professional)

Some of the key quotes extracted from the 'sorting' procedure are given in the Results section.

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.

RESULTS

Highlights from the interviews provide a rich insight into relevant issues. With respect to who championed the implementation of nD modelling, and what its value and degree of innovation was, Participant_02: Consultant noted that clients might eventually drive the use of nD and object models (such as IFCs), stating: 'If you demonstrate to the client that this gives them a level of understanding of their project and the ability to monitor that project... which adds value to them, then they will drive it!'

Another participant agreed that the client is, and should be, the driver for innovation. However, in this case, the respondent thought the client should also demand a more active approach to diffusion and implementation: 'In this industry we tend to be producing what the client wants, that’s the nature of the
beast. If there are tools in that process that enhance the work we do and add value then we will always be looking to use them, but most times the client will definitely drive it' (Participant_07: Contractor).

If innovation comes from within the AEC industry, a pertinent question is who innovates and who provides IT expertise? A view commonly held by various contractors’ representatives interviewed was that design consultants provide the IT ‘muscle’. However, some design consultants disagreed and emphasized that their documentation should be compatible with the systems that contractors work with. For example, one said: ‘But to get value out of something like this, it has to be across the process. Sometimes we are only involved in the initial part, sometimes we might be involved a bit more. If you look at the process timeline, you’ve got: concept, preliminary design and then... tender, detail design [this is the typical design and construct] and then construction. So we have little to say in the use of software... this would be more of a case for visionary consultants’ (Participant_02: Consultant).

A significant attraction of 4D modelling to contractors is the provision of facilities that enable them to obtain a ‘basic timeline’, thereby reducing the amount of time and effort needed to prepare a construction program [Q5]. Such systems provide an activity list that covers all the objects in the model. Another quote about the value that contractors attach to 4D and nD modelling is that: ‘...to obtain value out of this is not easy. They are more likely to use it at a conceptual level with consultants as a first cut schedule and take it from there to suit ...intended methods of working’ (Participant_01: Contractor).

FIGURE 7 Cross analysis of interviewees (from Adobe Acrobat Professional™)
As contractors, Participant_1 and Participant_5 regarded themselves as temporary contributors to the design and construction processes. For them it was ‘the client’ who may eventually promote the use of ‘product models’ and 4D CAD as they thought that clients would be able to benefit across the process. Their views on the current use of product modelling as a design, planning and management tool, included:

- provides an initial timeline for a project
- delivers documentation in 3D format
- does construction programming from 3D models
- uses 3D models as a graphical record against a timeline
- time savings benefits by running and analysing construction scenarios

Views of consultants on the value of object models include: ‘The concept of the object model has taken some time [to develop] but now it has been embraced by the practice. So now we are trying to exploit it in different ways, one in which objects could be presented as spreadsheets. ArchiCAD™ embraces the object model and Autocad™ people use essentially 2D drafting and layering – mainly those based overseas. We also use Adobe Acrobat Professional™ for checks and design reviews. The problem here is that all 3D information is lost once the files are saved as portable data files (PDF)’ (Participant_02: Consultant). Following this, Participant_02 noted that the concept of object models has taken some time to evolve but now seems to be working well. This participant currently finds value in exporting drawing and component data into spreadsheets which are then used for estimates and updates. In many cases, these documents are sent to contractors and suppliers.

GRID REPRESENTATION
In this study, repertory grids have been used to illustrate relationships between themes (or constructs) and participants (or elements). The theoretical background, use and interpretation of repertory grids is beyond the scope of this paper. For more information about repertory grids refer to Fransella and Bannister (1977) and Kelly (1955). A good introduction to the technique may be found in the work of Stewart (1980).

Figure 8 synthesizes the analyses of all 11 interviews and presents the data showing relationships between participants and interview themes. The full grid (Figure 8) shows both respondents and themes. The cluster patterns show links between bipolar themes and respondents.

Dendritic (or ‘tree’) diagrams have been used to present links between elements. Those shown on the right-hand side of Figure 8 indicate relationships between participants and themes. They illustrate the level of agreement between interviewees (e.g. individual matches at 100%, 90%, 80% and so on). Numbers one to 11 identify the interviewees and linkages have been established through key characteristics (or attributes) identified in the previous section. The attributes are plotted as bipolar constructs and each interviewee is identified either to one side or the other of the bipolar (or semantic) differential.

A strong linkage (e.g. 80%) indicates commonalities in the views or attitudes of the interviewees. Figure 8 indicates links at 59% and above. These links are based on proximities and tendencies identified during interview analyses. From Figure 8, three clusters can be identified:

- cluster 1: Participant_11 and Participant_02 (linking at 80%)
- cluster 2: Participants_01, 03, 05, 07 and 06 (linking at least at 76%)
- cluster 3: Participants_08, 09, 04 and 10 (linking at least at 60%).

Note that Participant_10, with a linkage of 60% with the rest of the cluster, represents the weakest link.

Clusters may be classified as follows:

- cluster 1 corresponds to interviewees with strategic views
- cluster 2 corresponds to interviewees with organizational views
- cluster 3 corresponds to interviewees with project views.

Figure 8 shows clusters identified in coloured patterns. These have been established between interviewees (1 to 11) and the themes they discussed (i.e. the relationship between the bipolar constructs). Note that
the clusters on the left-hand side of Figure 8 are predominantly white in colour whereas those located on the right-hand side are dark (or blue, if printed/displayed in colour). Colour blocks in the matrix indicate whether a participant relates more to the light (white) side or to the darker (blue) side. Left and right areas represent extremes of the same concept—a bipolar construct (Fransella and Bannister, 1977; Stewart, 1980). Grid clusters assist in identifying links between respondents (columns) and themes (rows).

Figure 8 shows matrix clusters and dendritic diagrams. The clusters highlight areas of commonality across themes and participants while the dendritic diagrams show relationships between participants and themes. Dendritic diagrams thus provide a graphical representation showing, for example, the percentage of similarity between rows or columns. A match of 100% means that two (or more) rows or columns have similar ratings. The dendritic diagrams are shown on the right-hand side of Figure 8.

The cluster grid (the chequered pattern in Figure 8) shows whether the interviewees relate to the right or left pole. For instance, interviewees 2 and 11 (cluster 1) relate to the right pole whereas interviewees 4, 8, 9 and 10 (cluster 3) relate to the left pole. Interviewees 1, 3, 5, 6 and 7 (cluster 2) share views from both poles (e.g., top of the grid is dark/right and bottom is light/left). Theme ‘clusters’ thus represent a collection of similar views.

Figure 8 provides a detailed representation of the links between constructs (or themes at level 3). For instance, it shows two constructs that match at 100%: ‘Contractor/Consultant’ (in row 9) and ‘Receive IFC data/Produce IFC data’ (in row 15). Interpreting these constructs’ proximity, there is a high likelihood that the contractor will receive IFC data whereas the consultant (or a third party) will create IFC data files. The contractor
is reluctant to generate models, including those from IFC’s databases, but values using them.

Other links that correspond to at least 80% (refer to Figure 8) and indicate a strong relationship include:

- (Corporate view/Project view) and (Decision maker/Executive). The proximity of these two constructs (at 93%) points to a relationship between the views of individuals at various organizational levels, and their views on how technologies can be implemented.

- (Corporate view/Project view) and (Familiar with 3D CAD/Only 2D CAD). The proximity of these two constructs (at 90%) indicates that the motivation to adopt 3D CAD comes from top management.

- (Decision maker/Executive) and (Communicates with client/Communicates with professionals). Conversely, the proximity (at 90%) between the constructs (Decision maker/Executive) and (Communicates with client/Communicates with professionals) raises issues about the use of tools to improve communication with clients or to improve communication with other professionals.

- (Familiar with 3D CAD/Only 2D CAD) and (Ready for IFCs/Only 3D CAD). The proximity of these constructs (at 90%) implies that, to achieve ‘product modelling’ (represented in the context of this paper as IFC functionality), the AEC industry needs to move from 2D CAD to 3D CAD. Grouped 3D CAD objects with embedded information can then be exported as IFC files. This encapsulates industry’s view of how product modelling could be incrementally embraced.

- (Consultant/Contractor) and (Produce IFC data/Receive IFC data). The nearness of these constructs (100%) may be interpreted as an expectation that consultants lead efforts to implement product modelling. On the other hand, consultants see this as a requirement to be provided at no extra cost, and at this stage see very little benefit to their organizations. Consultants consider that the skills needed to create IFC files are not yet widely available. For this reason consultants also see opportunities for third-party service providers (or research organizations such as the CRC CI) to lead the development and implementation of product modelling. The contractors interviewed saw themselves as ‘interested followers’ of nD technology. There was a strong feeling that they were not in a position to produce 3D models or IFC files as they do not have the in-house expertise required for such tasks. Furthermore, they argue that it is the responsibility of design consultants to motivate clients to use 3D CAD and IFC files by ‘educating’ them. This may be interpreted as an opportunity for consultants to measure and communicate the added value of nD technology to the AEC industry and its clients. To further illustrate this point, Participant_01: Contractor noted: ‘There are various systems that already exist but what you are doing here is putting things together and I suppose those are the areas where we could obtain value. I would see us being not a leader in it but an interested follower. I see it will be people doing conceptual design and preliminary design that would gain the most out of this and we do get involved in that phase but we do not do it directly, we do it working with consultants.’

Repertory grid constructs with strong linkages have been highlighted above. Other bipolar constructs can be identified from Figure 8. For instance, the construct (Practices can improve) and (Sceptic) refers to the two extremes between inclination and reluctance to engage in innovative practices. If this construct is compared against all participants, only participants 4 and 9 were reluctant to change, whereas participants 3, 5 and 6 showed a certain degree of scepticism (with values of 3 and 4 out of 5). Other participants showed more willingness to change current practices (with values of 1 and 2 out of 5) (see Figure 8).

Another example is that of (Communicates with client) and (Communicates with professionals). This relates to the use of 4D CAD and nD modelling as tools to improve communication, either with clients or with other professionals. Participant_11: Consultant noted that: ‘...this is of great use to synthesize project options with the client and say, “Here is an option, here is another one”, and it is at this stage when they see the possible outcomes of their requirements. In using product modelling approaches they see how this fits within overall project objectives.’
This aligns with the observations of Whyte (2001: 101) who found VR to be used for a range of tasks (e.g. to assist interactions with non-professionals and to communicate with other AEC professionals). The following quote highlights the value of 4D CAD and object modelling for contractors: ‘We communicate our plan to subcontractors in a number of ways. We have meetings with our subcontractor when we are signing them up and talk about the program[Q8]. The other way of communicating our plan is by co-ordination... once the project is on its way, we have regular meetings which are to facilitate co-ordination on the job but also to talk about the program...[Q8] and at this stage we don’t have CAD people. We can see the use of 4D CAD [would be] of great value to assist us at all stages of the process.’ (Participant_07: Contractor)

DISCUSSION

Results have shown that our AEC industry partners clearly identified the benefits and added value of nD modelling. The shift to 3D CAD by industry partners has been recognized as positive, especially for those contractors who translate information into spreadsheets. This is seen as a step towards implementing IFC files and object modelling technologies and procedures.

However, results have also indicated that interviewees foresee the implementation of object models as the result of incremental steps and not as a single breakthrough. For instance, the shift to 3D CAD, online shared CAD repositories and CAD integration with spreadsheets is seen as the result of ‘stepped’ improvements. This highlights the difficulties and challenges of motivating industry at all levels (from strategic to grassroots) and to actively engage in R&D processes and related training activities.

Managing expectations is another key issue. All respondents considered the production of object models to be labour intensive (especially producing and updating object libraries, such as IFCs). This is highly relevant as construction is a ‘project-based industry’ where data regularly need to be modified. Amor and Faraj (2001) found this consideration to be especially challenging for small and medium-sized enterprises (SMEs).

In the context of our investigations, the planning results derived from object models can only be used as first cut solutions and need to be reviewed and refined by experienced personnel. Data collected through interviews showed that neither contractors nor consultants wished to commit to the task of producing and updating IFC files. However, they both see third parties being involved in producing product models (or IFCs). Such third parties include specialist consultants, vendors or a governmental initiative. For the two industry partners interviewed, the CRC CI has been the only vehicle by which they could engage in the development and use of nD modelling technologies.

On implementing product modelling, there is a view that a rigorous construction methodology and logistics are key factors in winning projects and, in terms of object modelling, we have done some trials but it has been difficult with IFCs because there is not that much expertise out there. So you need to have a very special consultant to deal with. (Participant_05: Contractor)

Results also indicate that the use of IFCs and product modelling in the AEC industry is in its infancy. Some of the interviewees predicted that IFCs might take up to a decade to be fully consolidated (if IFCs were to become an industry standard). Amor and Faraj (2001) and more recently by Dawood et al (2003) support this view. A more optimistic view of IFCs, held by both contractors and consultants, is that the use of IFCs is an opportunity to ‘align’ the use of software and reduce power struggles associated with deciding who uses whose software. Our investigations highlighted a consensus, i.e. that design consultants spend time and resources on CAD systems, whereas contractors invest in programming and scheduling software. To the latter, the advantage of IFCs is that they will provide a means of enhancing connectivity.

Other relevant quotes include:

... we are not going to buy a really high-end programming system such as Primavera™ over here – we are just not going to get the value out of it. Then we can start to talk about a shared repository between us. So, on that basis, I think IFCs have a practical use. (Participant_02: Consultant)

... the contractor has the programming and scheduling (expertise) and not much CAD, whereas we have lots of
CAD and not much programming and what has been talked about in this project is two big ends open to each other. But I think there is a need for a case study made to assess the situation. This is our interest, this is their interest, but if IFCs sit in here and we have a shared repository, we can bring those two together. That would be attractive to both. (Participant_02: Consultant)

In this case, for example, we do not use Primavera™. Here we’ve got half the story but we use MS Project™. So this might be a two-tier situation, the big-end CAD and the small-end programming for us, and the big-end programming and the small-end CAD for a contractor. If our client is not using our type of software, we need to map-out data from our system into their system. (Participant_11: Consultant)

Now the challenge is to do this in real time. We have institutional clients and [need] to plan effectively... We do a lot of master planning to different levels such as security, traffic control, redevelopment work. Having a tool with the ability to show time issues and particularly redeveloping or discussing possible building scenarios can be of great value to us and to the project. (Participant_05: Contractor)

Industry’s views of the main potential benefits of nD modelling include applying product modelling and industry standards for construction documentation. The main deliverable of this Construction Planning Workbench project is an in-house software application that implements the principles of IFCs, facilitating the integration of CAD tools and programming software. The implementation of software, such as that described in this paper, will arguably serve to narrow the gap between the expectations of consultants and contractors.

CONCLUSION
Qualitative data analysis was used to identify the needs and expectations of product modelling (such as nD modelling) in the AEC industry, especially in relation to integrating CAD and programming software using IFC standards. The study has revealed industry views at strategic, managerial and operative levels.

Results show that design consultants are embracing the use of 3D CAD in a move to 4D and nD modelling tools and techniques. At this stage, both consultants and contractors see the benefits of converting 2D documentation into 3D models to improve design, planning and management of building and civil engineering projects. Our interviews elicited a positive response to 3D design documentation.

There was consensus among interviewees that the implementation of nD modelling technologies (such as IFCs) would be considerably eased if third parties produced them (as the processes involved demand specialist skills). These third parties could be private enterprises or an initiative such as the CRC for Construction Innovation. This issue is expected to be exacerbated for SMEs.

The views of one interviewee summarize the situation: ‘If it was our company on its own, we would not be doing it because we don’t get involved in R&D. We follow innovation and CRC CI is a vehicle where we can do this. We are not the primary driver.’ (Participant_08: Contractor)

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Stewart, P. *Strategic IT of Construction Companies*. Department of Building and Construction Economics, Melbourne, Victoria, Australia, RMIT University: 354. (2000). [Q18]


Authors queries

Q1 is this referring to a computer program or a programme of work?
Q2 Finch 2003 – this doesn’t appear in the ref list. But there is a Finch 2000?
Q3 Seidel, 1988 – this appears as Seidel 1998 in ref list
Q4 why does the Acrobat program need a reference?
Q5 is this referring to a computer program or a programme of work?
Q6 who is ‘they’?
Q7 as journal is printed in black and white, delete ‘(or blue, if printed/displayed in colour)’? Or is this necessary information?
Q8 is this referring to a computer program or a programme of work?
Q9 Anon. Acrobat Professional(B) v.6.0.1. Adobe Inc. NY (2004). Is this a publication or is it just referring to the computer program?
Q10 IT Con – give full name of journal

Q11 Mallasi – give initial. CONVR-2003 – are these proceedings from a conference? If so, give full title of conference and where it was held. Virginia Tech. – what is this?
Q12 CONVR-2003 – are these proceedings from a conference? If so, give full title of conference and where it was held. Virginia Tech. – what is this?
Q13 Fischer, M. and Kam – give place of publication and what the number ‘50’ refer to?
Q14 Fromm – why does a computer program need a reference?
Q15 Kim – what is this publication? Book, proceedings, journal? Give more details
Q16 Marshall-Ponting – what is this publication? Book, proceedings, journal? Give more details
Q17 Seidel, – give publisher and place of publication
Q18 Stewart 2000 – what does ‘RMIT University: 354’ refer to?
Q19 are these proceedings of a conference? If so, give details of title of conference.