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CRC Construction Innovation
B U I L D I N G O U R F U T U R E

Construction Planning Workbench

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Research Program C
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Construction Planning Workbench

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TABLE OF CONTENTS

TABLE OF CONTENTS	I
LIST OF FIGURES	II
PREFACE.....	III
EXECUTIVE SUMMARY.....	IV
Objective.....	iv
Findings	iv
Future Directions	iv
INTRODUCTION	1
LITERATURE REVIEW.....	1
Product modelling.....	1
4D Computer Assisted Design	3
Visualizing construction planning activities	5
PRODUCT AND PROCESS MODELLING	6
STEP in the construction industry	6
EXPRESS family of modelling language.....	7
Foundation of industry foundation classes (IFC).....	7
CONSTRUCTION SIMULATION	12
Simulation in Common Point	12
Simulation Using Bentley Navigator	13
Simulation in ArchiCAD	14
CONSTRUCTION PLANNING WORKBENCH TOOLS.....	17
Element, Activity, Resource and Sequence (EARS).....	17
Prolog-based intelligence server (PINS).....	20
IFC to VRML converter.....	24
CONSTRUCTION PLANNING WORKBENCH: BENEFITS AND ADOPTION.....	26
Data collection	26
CONCLUSION AND RECOMMENDATIONS	39
REFERENCES.....	40

LIST OF FIGURES

Figure 1 IFC product modelling.....	2
Figure 2 Mixed Reality Systems	6
Figure 3 Hierarchical relationships between a beam and other elements	10
Figure 4 Types of construction resources.....	11
Figure 5 Wire-frame image of a very simple building.....	13
Figure 6 Visualisation of the construction of previous figure.....	13
Figure 7 Flow of information in 4D visualisation in Common Point.....	13
Figure 8 4D visualisation of a construction sequence in Bentley Navigator	14
Figure 9 Construction Simulation dialog box in ArchiCAD 7.0.....	15
Figure 10 Stages in the simulated construction of a building in ArchiCAD 7.0	15
Figure 11 Construction stages of a trivial building as an illustrative example.....	18
Figure 12 state of the Java application window of CPW PINS	21
Figure 13 Loading rule base and connecting to the ODBC data source.....	21
Figure 14 Generating construction activities, resources and job logic.....	21
Figure 15 List of building elements	21
Figure 16 List of construction activities and their predecessors	22
Figure 17 List of required equipment and human resources	22
Figure 18 Opening an ODBC data source in MS Project.....	22
Figure 19 MS Project Import Wizard.....	23
Figure 20 Creating a new data mapping.....	23
Figure 21 Importing task information into a new project	23
Figure 22 Data mapping for the database table “MSPrj_Tasks”	24
Figure 23 Information flow for the generation of a VRML file from an IFC file	24
Figure 24 User interface for IFC to VRML conversion	25
Figure 25 Model for interview analysis (Seidel, 1998)	28
Figure 26 Code book and search for themes.....	29
Figure 27 Emergent clusters at level two.....	31

PREFACE

The Cooperative Research Centre for Construction Innovation (CRC CI) is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. 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 a seven-year project funded by a Commonwealth grant and industry, research and other government support. More than 150 researchers and an alliance of 19 leading partner organisations are involved in and support the activities of the CRC CI.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology (ICT) Platform*.

Each project involves at least two industry partners and two research partners to ensure collaboration and industry focus is optimised throughout the research and implementation phases. The complementary blend of industry partners ensures a real-life environment whereby research can be easily tested and results quickly disseminated.

The Construction Planning Workbench project in the **Management and Delivery of Built Assets** core area is envisioned to demonstrate the feasibility of deriving draft construction schedules from IFC data generated from 3D CAD models. The project is also geared towards the investigation of methodologies in automatically linking construction schedules with 3D CAD models to produced visualisation and simulation of construction schedules.

The project is a collaborative effort between CSIRO Manufacturing and Infrastructure Technology and The School of Architecture and Built Environment at the University of Newcastle, together with the project's industry partners: Woods Bagot and John Holland.

Woods Bagot, which was founded in Adelaide in 1869, is an international design practice with offices in Adelaide, Bangkok, Brisbane, Canberra, Dubai, Hong Kong, Kuala Lumpur, London, Melbourne, Perth and Sydney. The company specialises in the design of facilities for health, education, transport, retail, residential, hospitality, sport and leisure, specialist and IT, defence and commercial clients in the private and public sectors.

John Holland Group, which was founded in Victoria in 1949, is a diversified construction contractor and a provider of operations and maintenance services to the rail, telecommunications, building and heavy engineering sectors. John Holland has corporate offices in Melbourne and Sydney. The company's principal regional offices are located in Brisbane, Darwin, Melbourne, Newcastle, Perth, Sydney and Townsville.

EXECUTIVE SUMMARY

Objective

This report is an attempt to present the current state of product and process modelling in the building industry in general, and in construction planning and scheduling in particular. This report endeavours to describe what has been achieved by the Construction Planning Workbench (CPW) project.

Findings

This report shows that IFC data is a potential source of information in the generation of draft construction schedules. The report illustrates the feasibility of using logic programming to codify knowledge and trade practices in the construction industry. The use of logic programming, instead of other software development paradigms, allows the development of a flexible and expandable domain rule base. The research also highlights the viability of using commercial off-the-shelf (COTS) software (i.e. ArchiCAD, Common Point and Microsoft Project) together with custom developed software components (i.e. CPW – Prolog Intelligence Server, IFC to VRML Converter, Building Element Classifier and the Element Connectivity Agent).

Future Directions

The results obtained in this report are potentially useful in the development of practical and effective tools for generating draft construction schedules from 3D CAD models. The initial results of the CPW initiative can provide a framework for a practical approach to the partial automation of drafting construction schedules for full-scale projects. This framework is applicable to projects that are built on a repeated basis such as multi-storey buildings and highway bridges. One of the main goals of CPW is to capture industry knowledge and trade practices in construction planning and scheduling and thus maximising the benefits from this vast repository of knowledge and past experiences.

INTRODUCTION

Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. Developing the construction plan is a critical task in the management of construction.

The preparation of construction plans and schedules is a time consuming process. In the early stages of a project several plans may be developed to assess alternatives in sequencing, timing and the use of resources. During construction, the higher level plans need to be defined at greater levels of detail within the constraints imposed by the initial planning process and the evolution of the process itself. Consequently, improvements in the support for and speed of the planning of construction processes would improve the efficiency of the industry.

Current projects within the CRC-CI (such as 2001-007-C Information Flows & 2001-14-B Automated Code Checking) are using the Industry Foundation Classes (IFC) to define building elements during the “detailed documentation” stage of the building project and to check that the design meets requirements. It is an obvious extension of this work to start applying the IFC models to the construction process. A prospective area is in the use of the IFC to partially automate the development of project plans and schedules.

The IFC repository provides a catalogue of the building elements within the construction project. The construction activities associated to these elements can be automatically identified and automatically sequenced. This will provide a draft schedule that can then be imported into Construction Project Management software, such as Primavera or Microsoft Project for further analysis.

Planning and scheduling is required at several stages of a construction project. For design-construction projects, it may be required to win the initial contract using a conceptual design. Plans need to be developed during the tendering process with traditional procurement methods. In all procurement systems, more detailed plans are required before starting work on site and, at more detail, at monthly and weekly intervals throughout the contract. A system, such as CPW may substantially reduce the time required to develop and analyse construction schedules and hence can be a potentially valuable tool to the constructions industry stakeholders, such as CRC-CI industry partners.

Planning and scheduling of construction activities is also an error prone process where many factors need to be considered simultaneously. Studies have shown that the visualisation of the construction schedule reduces errors and improves the performance of inexperienced planners significantly. The sequencing information generated by CPW can be used in 4D CAD (3D + time or schedule) software so that users can see the sequences of construction activities on the virtual view of the construction project.

LITERATURE REVIEW

Product modelling.

Product models provide a radical step away from conventional design and visualization tools. Since the end of the 1990's most leading CAD developers started to shift from two-dimensional CAD to three dimensional CAD and object-based systems. Unlike traditional CAD, building components are created from lines and arcs, nD design and product modelling is executed in three-dimensions from the start (Finch, 2003). In nD environments, standardised building components are increasingly designed as objects and stored in on-line shared repositories. Some object models also include embedded information such as costs, safety codes, connectivity, strength, life cycle and other relevant attributes. The resulting

model becomes a detailed representation that can be displayed in many different ways (for example 3D models, spreadsheets, drawings, tables and so forth) to meet the information requirements of architects, engineers and constructors (Fischer, 2000).

The effectiveness of nD modeling relies on the interrelationships between various elements. By forming relationships between objects designers can begin to explore behavioural characteristics. Much of the information required to inform decisions is stored in these objects. By testing models, designers are able to run case or “what if scenarios” for development or to enhance build-ability (Heesom, 2004).

Standards have and are emerging to effectively govern nD (or product) models. Some of these include “Industry Foundation Classes” (IFC) and “Standard for the exchange of product model data” (STEP). IFC is a data protocol that seeks to create a common international “object library repository” (see Figure 1). STEP is similar. It is an ISO standard that arose as a result of multiple-industry collaboration to develop consistency. Both IFC and STEP provide a standard for exchanging product model data and to prescribe protocols for information requirements allowing specific activities to be performed (Kim, 2004).

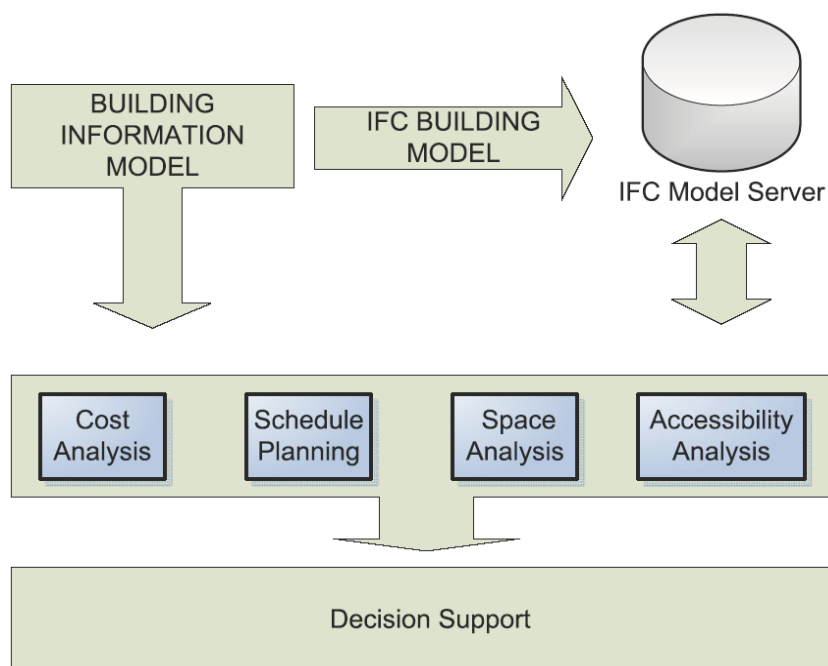


Figure 1 IFC product modelling

In this research, IFCs have been used to catalogue various building elements within a case-study project. The construction / placement of these elements can be automatically combined into activities, which can then be automatically sequenced. The software tool developed as part of this research provides a *first cut* schedule that can be imported into standard scheduling software (e.g. Primavera™, MS Project™) for further analysis.

The sequencing information may also be imported into 4D CAD (3D visualisation plus time) software such as Bentley Navigator™, Archicad™ and Common Point™ to enable users to peruse digital construction sequences for the building in question. With 4D CAD, information about the elements contained in a building is available at the end of the detailed design process through IFC data. The information about classes of building elements can then be combined to schedule activities (Fischer and Kam, 2000).

Kiviniemi (2002) suggests that the use of product modelling will take place in the construction industry as a result of the increasing use of the Internet. Finch (2000; p48) 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 this technologies provides a new way of working in architectural and engineering design”. This means that design and construction processes

can be fully integrated - with significant consequences. Such integration will enable several design professionals to be engaged simultaneously in a design process. This will fundamentally challenge our existing models of design.

The way interoperable data standards such as IFC (Lee, 2003) or STEP (Kim, 2004) operate is as follows:

The IFC protocol closely relates to the concept of product modelling, where building elements drawn on a CAD system are understood as three dimensional objects with 'n' properties (Katranuschkov, 2003). Thus if a wall is drawn on a building layout, the wall is understood as a volume which is composed of other volumes. Figure 1 illustrates some of the dimensions added to traditional 2D and / or 3D drawings through a 'product model'. In this case the product model is assembled through IFC's that contain cost, time, sequencing and safety information. The resulting product model can then be altered, modified and explored in a number of scenarios to evaluate outcomes and assist decision makers.

Human factors are of paramount importance when evaluating outcomes, making decisions and using object models because new tools (such as those described in this paper) involve changes to current ways of working (Dias, 2003). Human factors (such as ergonomics) need to be considered and applied if innovative tools and new working approaches are to be used effectively (Andersen, 2000). Fairuz, (2003) and Marshall-Ponting (2004) agree that product-modelling *actors* (such as the Architecture, Engineering and Construction [AEC] industry and clients) need to follow important aspects throughout the full design process including organisational training and education

Andersen (2000) recognised the need to intensively train clients, professional designers and construction personnel to familiarise them with new systems and ways of working. Furthermore, Stewart (2000) reported that training is the cheapest way of introducing changes of attitude within a highly conservative construction industry.

Whyte (2001) highlighted shortcomings of VR and product modelling to include the complexity of such systems and the need for highly qualified operators (which are rarely employed by small and medium enterprises [SMEs]). This aligns with the observations of Fischer (2000; p37) and Heesom (2004), who noted such deficiencies in the use of product modelling with clients and non-CAD specialists. Terrance (2001) found that to improve the uptake of nD and product modelling technologies, collaboration between the AEC industry, clients, technology providers and researchers was very important.

The role of the authors of this paper is that of 'knowledge generation'. This occurred by engaging industry throughout the software development process. The following sections describe consultations with our industry partners.

4D Computer Assisted Design

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. Schwegler 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.

Visualizing construction planning activities

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 to 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).

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 (Heesom, 2004). The latter are equipped with electronic agendas and wearable systems. Mixed Reality systems provide a

new, highly innovative medium for design and planning. Figure 2 illustrates the interaction between real and physical objects.



Figure 2 Mixed Reality Systems

PRODUCT AND PROCESS MODELLING

Product and process modelling is fundamental to most Information Technology (IT) developments in the Architecture, Engineering and Construction (A/E/C) domains. Developments in this area underpin the creation and deployment of design tools for the industry. Some important concepts in product and process modelling are discussed in Stumpf et al. (1996), and Froese (1996),

Engineers and builders continually build models, which enable them to assess a situation or scenario, and to communicate their vision of a future state and reasons for its desirability to others. Over the last few decades, significant progress has been made to model aspects of a building or structure with computer tools. Computer-interpretable models representing the product (building) and supporting a number of analyses and visualizations are now available.

The deployment of electronic links between parties involved in construction projects is likely to improved coordination and control. Electronic Data Interchange (EDI) is the most commonly used approach in the exchange of electronic information, EDI is defined as “*the transfer of electronic data using an agreed standard*” [Almeida et. al. (1998)]. EDI (Electronic Data Interchange) can also be defined as a generic term used for the electronic transfer of data from one software program to another.

Although EDI is widely used in several industries like automotive, retailing, distribution, banking and transportation, the level of EDI use in the construction industry is low and limited to groups of builders and suppliers. The two areas in the construction industry that are particularly suited to EDI are special construction methods and trade partnering.

Prefabrication, preassembly and modularization are special construction methods that are becoming more common on industrial construction projects. EDI has the potential to enhance procurement on these types of projects to take advantage of the economies realized with EDI applications in manufacturing.

EDI also forces companies to develop closer relationships with trading partners. The outcome of this process will probably be more partnering agreements between engineering and construction firms and their major suppliers. The resulting cost savings introduced by improved schedule deliveries, inventory reduction and procurement efficiency will be impressive.

STEP in the construction industry

Standard for the Exchange of Product Model Data (STEP) is an international product data standard (ISO 10303) to provide a complete, unambiguous, computer-interpretable definition of the physical and functional characteristics of a product throughout its life cycle. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

What makes STEP different from earlier data exchange standards such as IGES and DXF? The immediate advantage of STEP is its effective support for the exchange of solid modelling data. The long-range advantage is that STEP provides support for complete product life-cycle data exchange including design, manufacturing, application, maintenance and disposal. It is a much broader standard than data interchange standards such as IGES since it is intended to support product data throughout the lifecycle of a product including engineering, manufacturing and support data. This aspect of STEP makes the standard suitable, not just for IGES-style data exchanges, but also for implementing an integrated product information database that is accessible and usable to all the organizations and individuals involved in supporting a product over its lifetime.

Product data definition in STEP standards is written EXPRESS data definitions language. Thus STEP standards are computer interpretable. EXPRESS itself is a lexical object flavoured information modelling language and is defined in ISO 10303-11:1994. EXPRESS is used in many other activities outside STEP. For example, EXPRESS is used in the EDIF standards for electronic printed wiring boards. Other examples include asset management by the London Stock Exchange, the Human Genome Project, and ISO TC 211 for Geographic Information Systems

EXPRESS family of modelling language

EXPRESS was originally developed to provide a formal method of defining the data necessary to describe a product (i.e. a microchip or a high-rise building) throughout its lifecycle, from time of conception through its manufacture to its time of disposal. There are basically two aspects to EXPRESS:

- It provides for the modelling of data and data relationships with a very general and powerful inheritance mechanism, which is much more than is provided in Object-Oriented programming languages, and
- It includes a full procedural programming language that is used to specify constraints on data instances.

EXPRESS models may be written in the style of Entity-Relationship, CODASYL, Relational, Object Oriented, or other kinds of data modelling. It may also be considered to be a Set Theoretic specification language. Models described using EXPRESS are intended to be implementation independent. EXPRESS has borrowed from many other languages including Ada, Algol, C, C++, Modula-2, Pascal, PL/I and SQL. It straddles both programming languages and database specification languages. Being lexical, the language can be compiled, and there are a number of both commercial and public domain compilers available. Typically, these compile EXPRESS into another high-level language. Compilers have been developed for C, C++, Java, Prolog, and DDL (Data Definition Language) for both relational and object-oriented databases, such as Oracle, Object-Store, Versant and SQL Server.

Express is actually a family of modelling languages. The EXPRESS Language Reference Manual also defines a graphical subset of the lexical language called EXPRESS-G. Note that , EXPRESS-G is a subset of EXPRESS, as it does not include the constraint portions of the lexical language. The third member of the family is called EXPRESS-I and is a lexical language for the display of data instances and also for the formal definition of test cases. A fourth member of the family, called EXPRESS-X, is a mapping language for data translation between two EXPRESS models that are similar in semantic meaning but which differ in their data forms. Other variants and extension of EXPRESS include: EXPRESS-P, an extension for process modelling and the two older variants of EXPRESS-X namely; EXPRESS-M and EXPRESS-V.

Foundation of industry foundation classes (IFC)

With the increasing interest in building information modelling in the AEC community, the issue of interoperability as a means to integrate the various model-based applications into a smooth and efficient workflow has emerged. One emerging standard for interoperability is the IFC ("Industry Foundation Classes") developed by the IAI ("International Alliance for

Interoperability"). International Alliance for Interoperability (IAI) is a worldwide consortium aiming to define the requirements for software interoperability in the AEC/FM industry. The deliverables of IAI are the specifications of Industry Foundation Classes (IFC TM) - an object oriented software library for application development. Many leading software suppliers are committed to release compliant systems.

Unfortunately, while technical information about the IFC building model is documented in detail and is readily available for software developers who need to work with it [IAI (2003)], there is practically very little information for the average AEC practitioner who wants to have a better understanding of the IFC model [Khemlani (2004)].

The IFC system is a data representation standard and file format for defining architectural and constructional CAD graphic data as real-world objects. The IAI's IFC system comprises a set of definitions of all the objects to be encountered in the building industry, and a text based structure for storing those definitions in a data file. A plain text file is used because that is the only truly universal computer data format. Then each producer of a CAD product can store their own data in whatever compact binary file format they wish to best suit their system. In addition they provide "Save As IFC" and "Read IFC" options, which map the IFC object definitions to the CAD system's representations of those objects.

Historical Perspective

While geometry-model based applications are still widely entrenched in the AEC industry, object-based data model exist within the current AEC software products. Graphisoft's ArchiCAD was developed more than 20 years ago based on an object-based building data model; so is the more recent Autodesk Revit. There are also hybrid applications such as Bentley Architecture and Autodesk Architectural Desktop, which have a building data model built on top of the geometric data model of the original CAD applications, MicroStation and AutoCAD respectively. All these are applications by commercial vendors and their internal data models are proprietary, which is why they cannot communicate their rich building information directly with each other unless they develop specific translators for this purpose.

The IFC is a similar object-based building data model that is, however, non-proprietary. It has been developed by the IAI, a global consortium of commercial companies and research organizations founded in 1995.

The IFC model is intended to support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. It was specifically developed as a means to exchange model-based data between model-based applications in the AEC and FM industries, and is now supported by most of the major CAD vendors as well as by many downstream analysis applications.

The IFC effort closely parallels another collaborative representation effort known as STEP (STandard for the Exchange of Product model data). Initiated in 1984 by the International Standards Organization (ISO), STEP was focused on defining standards for the representation and exchange of product information in general. Several people involved in the STEP effort from the building industry realized that a more domain-specific model was needed for representing building data. They subsequently got involved with the IFC development effort. The IFC model continues to be closely related to the STEP standard. It uses several resource definitions based on STEP and also uses the same modelling language, EXPRESS, for developing and defining the model.

Product modelling in IFC

A data model in any given domain describes the attributes of the entities in that domain as well as how these entities are related to each other. Since all computer programs deal with some kind of data, they must have some kind of underlying data model. Traditional 2D CAD and generic 3D modelling programs internally represent data using geometric entities such as points, lines, and rectangles (or boxes and plane is 3D). While these applications can

accurately describe geometry in any domain, they cannot capture domain-specific information about entities. To overcome the limitations of general-purpose geometric representations, every design-related industry has been developing and using object-based data models that are specific to their domain. In the case of the building industry, this translates to a data model that is built around building entities and their relationships to one another. Geometry is only one of the properties, among others, of these building entities; thus, its primacy is greatly reduced, even though the interface to creating the model is still mainly graphic. Such a data model is rich in information about the building that can be extracted and used for various purposes, be it documentation, visualization, or analysis.

A simple example of the difference between a geometric data model and a building data model can be illustrated in the representation of a beam. Geometrically, a beam can be represented as a rectangular prism (a solid figure in which all six faces are rectangles). Unfortunately, most slabs, columns, footings and walls are also represented as rectangular prisms. This situation is one weakness of a geometric data model. The model is unable to represent domain specific concepts. On the other hand, a beam in the IFC data model is a much richer concept. A beam (`IfcBeam`) is a horizontal structural member. It represents a horizontal, or nearly horizontal, structural member designed to carry loads. A beam has a geometric representation (i.e. a rectangular prism) but it has also other properties such its material and its relation to other building elements or group of elements.

A beam (`IfcBeam`) is a type of building element (`IfcBuildingElement`), which consists of all elements that are primarily part of the construction of a building (i.e. walls, beams, doors, or other physically existent and tangible things). A building element is a type of general element (`IfcElement`), which is defined as all components that make up an AEC product. Elements are physically existent objects, although they might be void elements, such as holes. Elements either remain permanently in the AEC product, or only temporarily, as formwork does. Elements can be either assembled on site or pre-manufactured and built on site. An element also includes a group of semantically and topologically related elements that form a higher-level part of the AEC product. An example of element assembly is stairs, composed of flights and landings. Figure 3 illustrates the hierarchical relationships between a beam and other elements.

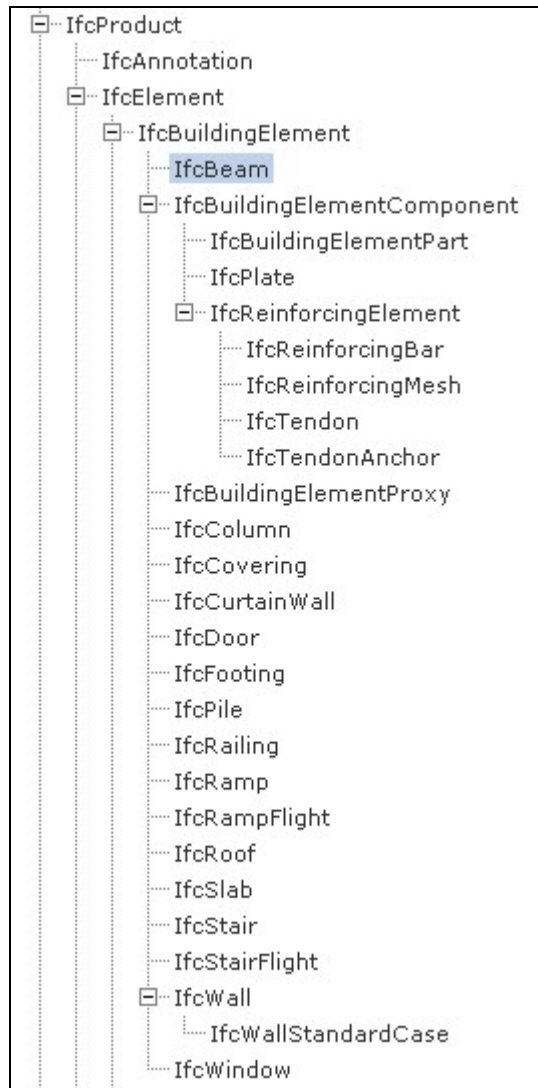


Figure 3 Hierarchical relationships between a beam and other elements

Process modelling in IFC

The IFC model represents not just tangible building components such as walls, doors, beams, ceilings, furniture, etc., but also more abstract concepts such as schedules, activities, spaces, organization, and construction costs. The IFC model contains entity definitions for concepts specific to individual domains. The latest release of the IFC consist of 9 domains, namely; Architecture, Building Controls, Construction Management, Electrical, Facility Management, HVAC (Heating, Ventilation and Air Conditioning), Plumbing & Fire Protection, Structural and Structural Analysis.

A process in the IFC data model is defined as any action taking place in building construction with the intent of designing, costing, acquiring, constructing, or maintaining products or other and similar tasks or procedures. Processes are placed in sequence (including overlapping and parallel processes). Processes can have resources assigned to it using IfcResources (see Figure 4).

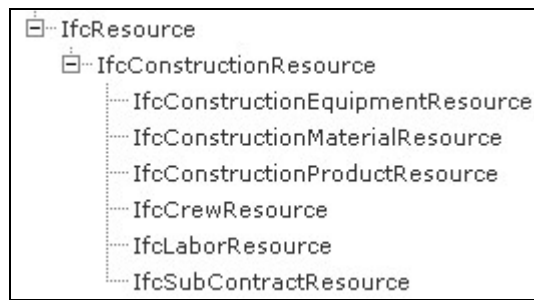


Figure 4 Types of construction resources

A process is typically task (IfcTask), which is defined as identifiable unit of work to be carried out independently of any other units of work in a construction project. A task can nest other tasks as sub-items. For example, the construction of a reinforced concrete beam may be designated as a nesting task named “construct beam #123”, which would includes other tasks such as “install formwork”, “place reinforcement”, “pour concrete”, “cure concrete” and “strip formwork”.

The data model also defined IfcProcedure. An IfcProcedure is an identifiable step to be taken within a process that is considered to occur over zero or a non-measurable period of time. Similar to tasks, procedure can also be nested. Sequential relationship between procedures is also defined.

CONSTRUCTION SIMULATION

Construction process planning typically means scheduling and schedules in “Gantt Chart” format. This kind of a schedule is not a particularly good commutation means for individuals having different background and being not necessarily familiar with formal scheduling outputs. It is essential to build trust between project parties and give the owners and users possibility to analyse and give feedback of the construction process plans.

The main reason for problems originating from project planning is due to the individual's misconception of reality. Thus, particularly in the case of multi-storey buildings one needs to have a good sense of 3D view in order to prepare the necessary plans. To increase the quality of the process plans better models and simulations of the construction process are needed. This is a one way to decrease the duration of the projects and same time keeping up the certainty that the schedule is realistic. Anecdotal evidence has shown that construction simulation using 4D CAD is indeed a good visualization and schedule review tool.

Simulation in Common Point

Common Point 4D is a professional 4D Viewer and Producer for visually building and viewing 4D models. Common Point 4D includes many features to quickly build and view 4D models and update and edit 4D models.

In order to create a 4D model in Common Point, a VRML (Virtual Reality Modelling Language) file that describe the geometry of the 3D model and a text file for the schedule must be imported into Common Point.

The VRML file describes the geometry of the model. The geometry different elements constituting the building (i.e. slab, column, wall, beam) is described using a box or an indexed face set. A box describes the element dimensions in the three directions. The Indexed Face Set gives the coordinates of all the vertices and then describes each face using the number of the vertices.

The VRML file has to satisfy a few requirements in order to be compatible with Common Point. It can only have objects described as boxes or Indexed Face Set. Other shapes such as spheres, cones and others are not acceptable. Spaces are required before each “{” and “[”. Although local coordinates for vertices are allowed in VRML, Common Point requires that global coordinates be used.

It is possible to import any comma-delimited or tab-delimited file in Common Point that has the following fields:

- Activity Description: Name for activity
- Unique ID: Some unique identifier so that updates of the schedule are possible
- Start field
- End field

The input file can be generated from Project Management software Primavera and Microsoft Project. It is also possible to directly create a text file with the required information.

The detail of the 3D building model should match the detail in the construction schedule. For example, if the schedule has activities such as "Pour concrete for slab in floor 1" then the 3D building model should have an element or group of elements representing the slab on the first floor. If the schedule has an activity "Pour concrete for slab in floor 1 - section 1" then the 3D building model should have elements representing the individual sections.

Consider the example of a building as shown in Figure 5. It is a 2-storey reinforced concrete building with six-pad footing as foundation. The building consists of beams, columns, footings, slabs and walls. Figure 6 illustrates various stages of the construction of the simple building. The flow of information is summarised in Figure 7.

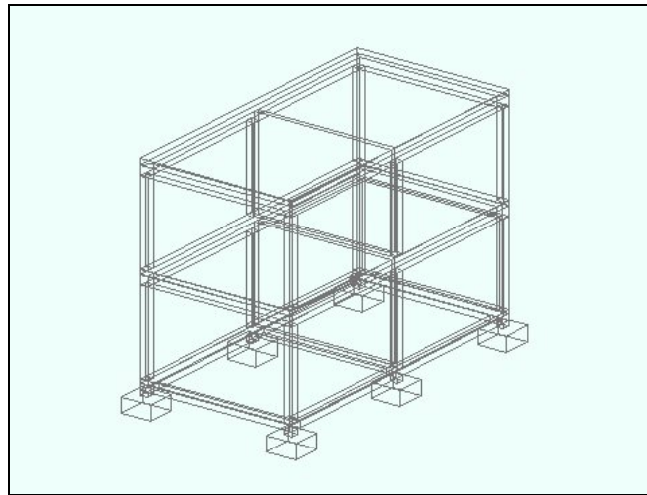


Figure 5 Wire-frame image of a very simple building

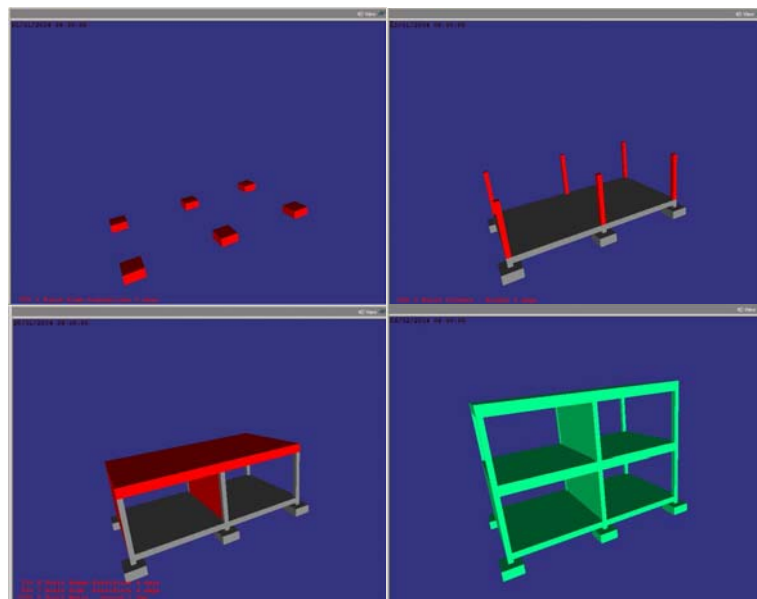


Figure 6 Visualisation of the construction of previous figure

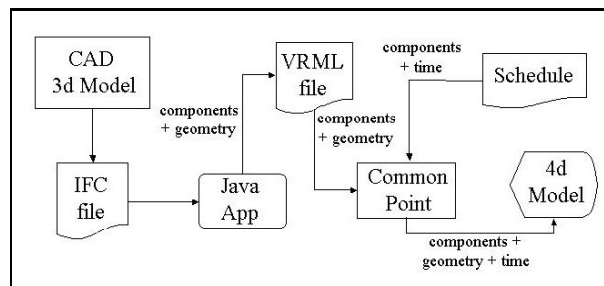


Figure 7 Flow of information in 4D visualisation in Common Point

Simulation Using Bentley Navigator

Bentley Navigator is an application for visualizing and navigating graphical and non-graphical facility information. It displays 3D models for interactive navigation and review or for querying of information from operations, scheduling, purchasing and other external systems. A simple interface broadens information access to those without CAD expertise.

It can visually simulate the construction process by integrating detailed 3D models with critical scheduling and planning information. Provide project managers with actual versus

planned construction comparisons, analysis of construction issues, improved design and procurement strategies, and exploration of alternative dispute resolutions.

Bentley Navigator is a real-time 3D visualization program that enables to view and interact with JSpace models and related data. JSpace is the object-oriented technology developed by Bentley Systems, Inc. The JSpace object model files can be created and edited using the JSpace Class Editor.

JSpace has interfaces with CAD systems, such as MicroStation and AutoCAD, and with database systems, such as Microsoft Access, Oracle, and SQL Server.

A DGN file created by a CAD system can be exported to a JSM file using the Interference Manager in MicroStation TriForma.

The schedule is also a JSM file that contains information from an external Primavera schedule or an external Microsoft (MS) Project schedule. To create a schedule based on an external MS Project schedule, data must be imported from an existing MPP file into a JSM schedule model. If the external MS Project schedule is modified, JSM schedule model must be updated.

As in Common Point, a graphic model object must be linked to a schedule activity object in order to perform a 4D simulation, Figure 8 shows a sequence of construction steps in the 4D visualisation done using Bentley Navigator.

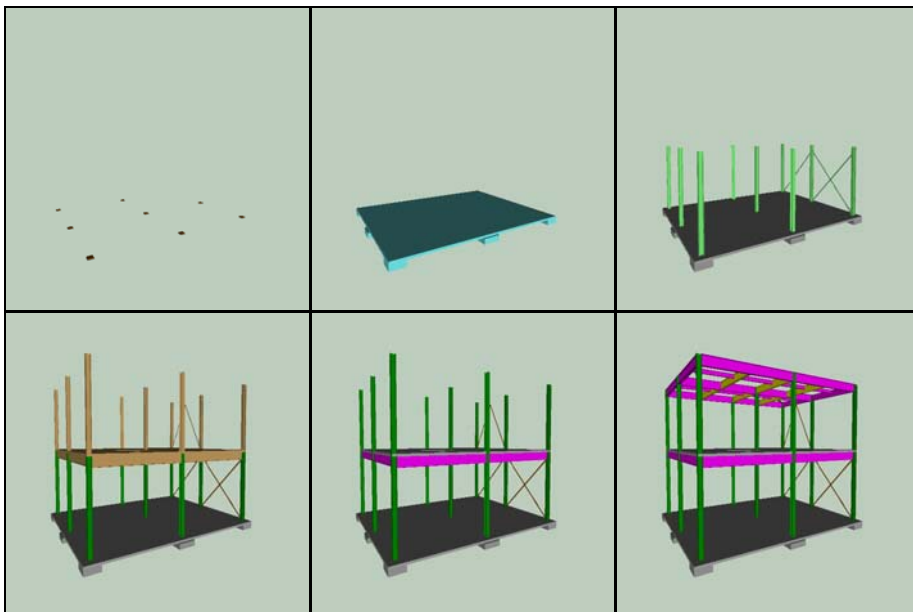


Figure 8 4D visualisation of a construction sequence in Bentley Navigator

Simulation in ArchiCAD

A major addition to ArchiCAD comes in the form of a task-based construction simulation module. By linking to Microsoft Project, ArchiCAD can generate still images of building status by date or produce animations of construction over time. Construction Simulation hierarchical menu allows users to simulate the construction process with ArchiCAD 3D model by associating construction elements to a task list. This list can be created within ArchiCAD or imported from a Microsoft Project database.

The Construction Simulation dialog box (see Figure 9) includes the following fields: Tasks, Type, Progress, Start Date and Finish Date. Fields can be edited by double-clicking in them. Clicking on any header will sort the task list by that key.

The Tasks, Start Date and Finish Date fields are imported from MS Project. The Progress field is automatically filled by ArchiCAD to conform to the Current Date defined at the bottom of the dialog box. Otherwise, this field is not editable.

Types are defined manually with a pop-up menu listing task types. There are five types of construction tasks:

- **Build:** Elements do not exist when simulation starts. They are constructed during the task and then remain there.
- **Demolish:** Elements are present on the site when simulation starts. They are removed during the task.
- **Restoration:** Elements that are present both at the start and the end of the task. Work is performed on them during the task.
- **Freeze:** Elements that are present both at the start and the end of the task, but no work is performed on them.
- **Temporary:** Elements that are not present when simulation starts. They are constructed during the task and are removed at the end of the task.

Tasks	Type	Progress	Start Date	Finish Date
Foundation	Build	100%	30/04/2004	7/05/2004
Level 1	Build	100%	7/05/2004	14/05/2004
Level 2	Build	100%	14/05/2004	21/05/2004
Level 3	Build	100%	21/05/2004	28/05/2004
Level 4	Build	62%	28/05/2004	4/06/2004
Level 5	Build	0%	4/06/2004	11/06/2004
Plant	Build	0%	11/06/2004	18/06/2004

Current Date: 2/06/2004

Buttons: Link, Unlink, Show Linked Tasks, Select Linked Items, Select Unlinked Items, New Task, Delete Task, Show Built, Show All

Figure 9 Construction Simulation dialog box in ArchiCAD 7.0

With the Construction Simulation tool ArchiCAD users can assign time parameters to each element of the Virtual Building and visualize the status at any given time, even create an animation. Figure 10 illustrates the simulated stages of the construction of a 5-storey building.

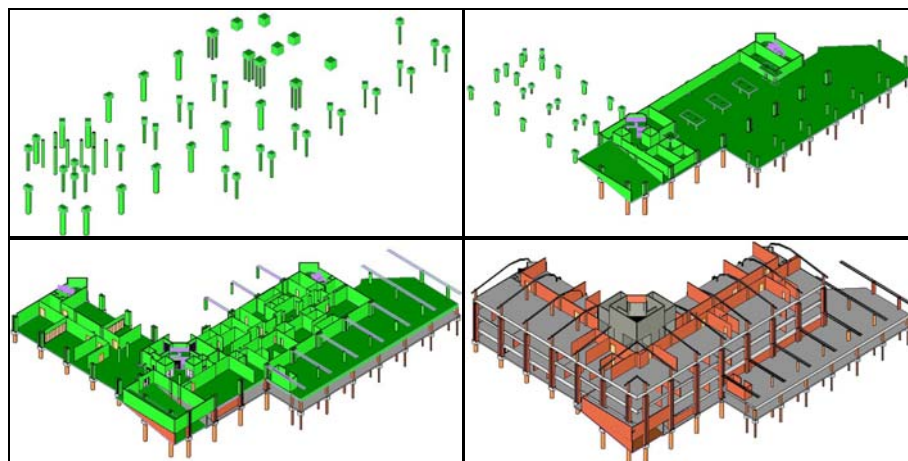


Figure 10 Stages in the simulated construction of a building in ArchiCAD 7.0

Collaboration with CIFE at Stanford University

Discussion between members CSIRO software development team for CPW and Dr John Haymaker from CIFE resulted to a more in-depth understanding of Common Point and VRML among the CSIRO developers. Discussion includes some properties available from VRML but that are not in the browser used by Common Point. The most important one being the availability of creating some properties in a group that can then be reused by the call to the group name. This is possible in VRML, but each time this has to be redefined to use the

file for Common Point. As an example, it is possible to define the colour grey if the material is Concrete, and then call this property each time a component is made of concrete. This would reduce the computation time as well as the size of the file.

Another example that was considered for the conversion from IFC to VRML was to use this property for generating geometrical objects that can be called by different components. It is the way that geometry is associated in the IFC file. This way of doing it was considered so that the data could be got straight from the IFC file without using EDM Database.

But as Common Point does not allow the reuse of block, it was necessary to use a different way for computation.

Another point discussed was about topology. Hence some elements in IFC are described with concave polygons, such as the base of an I-beam. When describing the vertices that define the edges of the polygon, the polygon would not be rendered, as it should. This is actually due to the fact that Common Point cannot render concave polygons, but only convex. We thus discussed the way that would make it possible to render them properly in the viewer.

The team also discussed some features that are available in Common Point and that help visualizing the construction more efficiently. By knowing those features, it was possible to make some modifications in the code so we could automate them. As an example, it is possible to add some fields when importing the schedule, such as resources used, which allows to see when they are used, or also which kind of activity is used. Hence, it is possible to have different activities types, such as permanent construction, temporary, demolish...and it is possible to add others as needed. By importing them, it is then possible to display them in a different colour in the viewer so that we can see straight away what type of activity it is, which gives a enhanced feed-back.

In the new version (Common Point version 1.95), many features are improved such as the possibility of timed snapshot. That allows us to see the building during its construction at different moments. Also it is possible to create movies, of the evolution of the construction of the building or of the whole window.

Another interesting feature is the possibility of comparing 2 schedules for a same building, in the same window or across 2 windows. Hence this allows to see which schedule is the best or the most suitable for the application.

CONSTRUCTION PLANNING WORKBENCH TOOLS

Previous works have tried to integrate the building product model with the construction process model [Fischer and Froese (1996)]. They presented three important concepts: building product component, construction process component, and the association between the product component and process component. A possible application of this association between building product and construction process is to automatically generate a construction schedule using some sort of knowledge-based reasoning engine [Chevallier and Russell (2001)].

The goal of this technical report is to demonstrate how a logic programming language, such as Prolog, with a rule base, in order to generate draft schedules automatically. The rules serve to capture domain knowledge such as basic construction principles and standard practices with the industry.

Forming a construction plan is a backward reasoning exercise where the required steps (i.e. construction activities) are identified to yield the desired result (i.e. completed building structure). The planning process begins with a result (i.e. a building design). Essential aspects of construction planning include the generation of required activities, and the analysis of the implications of these activities.

The programming language Prolog (for Programmation et Logique or Programming in Logic) has its own reasoning engine [Sterling and Shapiro (1988)]. Prolog reasoning engine is a backward-chaining procedure using depth-first search algorithm on ordered facts and rules until a solution is found.

The similarity in the reasoning style of Prolog and the required mode of reasoning in construction planning is a strong motivation in investigating the use of Prolog in implementing a software-based workbench for construction planning.

Element, Activity, Resource and Sequence (EARS)

A construction schedule typically represents a sequence of multiple teams (i.e. trades) that perform individual and distinct work while sharing common workspaces and resources. The logic or rationale behind the sequence of activities in a schedule is referred to as job logic. Job logic includes physical relationship between building elements or components (e.g. a column supports a beam), work team interactions (e.g. concrete work team and carpenters), or safety and code regulations (e.g. workers in a lower level should be protected from activities above them).

The start of some activities obviously depends on the completion of other activities. However, some activities may be independent from other set of activities and may proceed concurrently. Much of job logic follows from well-established work sequences that are standard in the trade. Nevertheless, there is generally more than one approach and no unique order of activities in any significant construction project.

The job logic between construction activities can be divided into fixed logic and soft logic. Fixed logic, such as the relation between installation of the reinforcing bars and pouring of concrete, will not change in any sensible construction process. Soft logic, such as at which end of a bridge should construction start may depend on various factors.

The basic goal of using logic programming is to capture both basic construction principles and local industry practices in order to provide a guideline in generating initial construction schedule.

An illustrative example

Consider a trivial example of a structure consisting of 4 pad footings, 8 columns, a stiffened raft (ground slab with 4 edge beams), a suspended beam and slab floor (with 4 beams), 4

beams (with no slabs), a roof and a wall as shown in Figure 11. All elements are of in-situ reinforced concrete construction except for the wall, which is of block work construction.

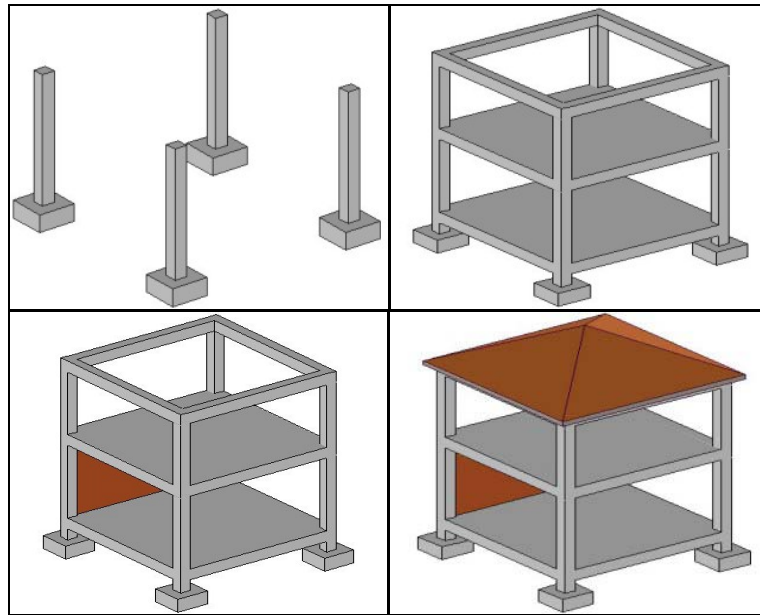


Figure 11 Construction stages of a trivial building as an illustrative example

Observe that the resulting schedule, as shown in Figure 11, allows all in-situ concrete construction to be done continuously. This may be beneficial if a single sub-contractor does all concrete works.

Prolog Structures

Prolog is a logic language that is particularly suited to programs that involve symbolic or non-numeric computation. It is a frequently used language in Artificial Intelligence where manipulation of symbols and inference about them is a common task [Bratko (1986)]. Prolog consists of a series of rules and facts. Additional facts, called derived facts are computed from rules and known (i.e. given) facts.

A Prolog program execution is basically presenting a query and solving it using known rules and facts. For example, consider the following facts about building elements and their connectivity:

```

% Building Element
% element(id, element-type, storey,...)
element(c201,'column',2, ...).           % Element c201 is a column in level 2
element(s301,'slab',3,...).              % Element s301 is a slab in level 3
% Element Connection
% connected(id, d)
connected(c201,s301)                     % Element c201 is connected to s301
    
```

Consider also the following rule about support relation between elements:

```

% Support Relationship
support(X,Y) :-
    element(X,'column',Lc,...),           % X support Y if ...
    Ls is Lc+1,                           % X is a column in level Lc
    \+ ground_level(Ls),                  % Ls is the level just above Lc
    element(Y,'slab',Ls,...).             % Ls is not the ground level
                                           % Y is a slab in level Ls
    
```

The rule above can be interpreted as *“If a column is connected to a slab, the column is just below the slab, and the slab is not a ground slab, then the column supports the slab”*.

Given a query:

```
support(X,Y)?                                % Find pairs of (X,Y) such that X supports Y
```

Such a query will result to: X = c201 and Y = s301

Other types of relationships between elements can also be defined using rules in Prolog. For instance, a “*constructed together*” relation can be written as:

```
% Together Relationship
together(X,Y) :-
    connected(X,Y),
    element(X,'beam',...),
    construction(X,'in-situ RC'),
    element(Y,'slab',...),
    construction(Y,'in-situ RC').
% X is constructed together with Y if
% X is connected to Y
% X is a beam
% X is an in-situ RC beam
% Y is a slab
% Y is an in-situ RC slab
```

The rule above can be interpreted as “*Beams and slabs in a reinforced concrete floor are constructed together*”.

Derived relationships such as “*support*” and “*together*” can in turn be use to derived other relationships such as “*constructed before*”.

```
% Precedes Relationship
precedes(X,Y) :-
    support(X,Y),
    \+ together(X,Y).
% X is constructed before Y if
% X support Y
% X is not constructed together with Y.
```

Elements and Associated Activities

Associating a set of construction activities to a building element or a group of building elements is a critical step in automatically generating workable job logic. The set of activities associated with a particular building element (i.e. column, slab, beam, or wall) depends on the construction method (i.e. reinforced concrete, steel frame, pre-cast concrete, or composite construction).

For example, the following are activities typically associated with reinforced concrete construction written as Prolog facts:

```
% Construction Activities
activity(1,'formwork').
activity(2,'place reinforcement').
activity(3,'pour concrete').
activity(4,'wait and cure concrete').
activity(5,'strip formwork').
```

Activity templates are used to associate the sequence of activities to a particular combination of building element and construction type. For instance, consider the following Prolog rule and facts:

```
% Element-Activity Pair
element_activity(X,A) :-
    element_activity_list(X,L),
    member(A,L).
% Element-Activity List
element_activity_list(X,L) :-
    element(X,T,...),
    construction(X,C),
    activity_template(T,C,L).
% L is the list of activities associated with X
% T is the element type of X (i.e. X is a slab)
% C is the construction method of element X
% Activity Templates
activity_template('slab','rc',[1,2,3,4,5]).
activity_template('column','rc',[2,1,3,4,5]).
....
```

Note that for reinforced concrete columns, the activity template specifies that the reinforcement be put in place before the formwork while for slabs the formwork comes before the placement of reinforcement.

Activities and Resources

Construction resources in traditional construction management views are divided into three categories, namely, labour, material and equipment. These are inadequate for constructability review of the schedule. In recent years, construction space was identified as another important resource type in construction planning. The important role of construction space in construction planning has been illustrated in several studies. Such as: Space occupation as a resource constraint [*Thabet and Beliveau (1994)*], Space scheduling model [*Riley and Sanvido (1997)*], and Time and space conflicts [*Akinci et al. (2002)*].

The definition of construction activities can be extended to include required equipment resources. For example, `activity(3,'pour concrete')` can be extended to `activity(3,'pour concrete','concrete mixer')`. Unfortunately, the required equipment may vary depending on the element type and its location. For instance, pouring concrete on a ground slab may also require a trowelling tool/machine while pouring concrete above ground level may require concrete pump and/or crane. Hence, an activity may have two hierarchies of required resources: the minimum resource requirement (i.e. concrete mixer) and the conditional resource requirement (i.e. trowelling tool).

Identifying the required resources for a given element-activity pair is part of the domain knowledge and can be written as Prolog rules as follows:

```
% Element-Activity-Resource Triples
element_activity_resource(X,A,R) :-
    activity(A,_,ResList),
    member(R,ResList).
element_activity_resource(X,A,'trowelling tool') :-
    activity(A,'pour concrete',_),
    element(X,'slab',L),
    ground_level(L).
```

Other traditional resources such as material and labour can be handled in the same way equipment resources are processed as described in the previous section. In fact, even a more abstract concept such as time-space constraints can be dealt with in a similar manner.

Prolog-based intelligence server (PINS)

CPW Prolog-based intelligence server (PINS) is the core of the Construction Planning Workbench (CPW) collection of software tools. The CPW-PINS module is a full-featured Prolog server for applications written in Java. It can potentially support C, C++, Delphi, and Visual Basic applications. It incorporates domain rules in the construction planning area. The rules in PINS are designed to identify:

- A list of building elements supporting a given building element
- A list of building elements that should be constructed together
- Activities & resources associated with a building element
- Precedence relationship between activities (job logic)

Using CPW PINS

CPW PINS start with a Java application window shown in Figure 12. The “Load CPW” button instruct the intelligence server to load the rule base and connect to the ODBC data source (see Figure 13). Analysis of the building data can be done once the rule base and database are loaded (see Figure 14). The analysis consists of generating associated construction activities for each building elements and the required resources. The precedence

relationships (also called job logic) among the generated activities are also defined during the analysis.

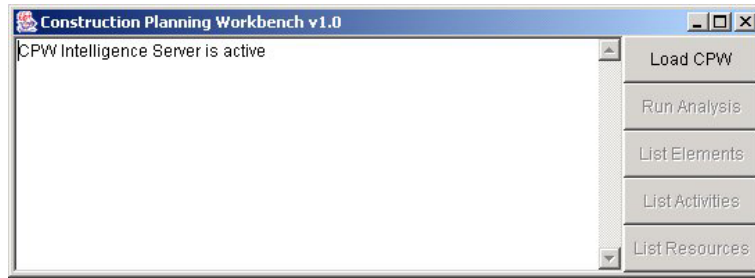


Figure 12 state of the Java application window of CPW PINS

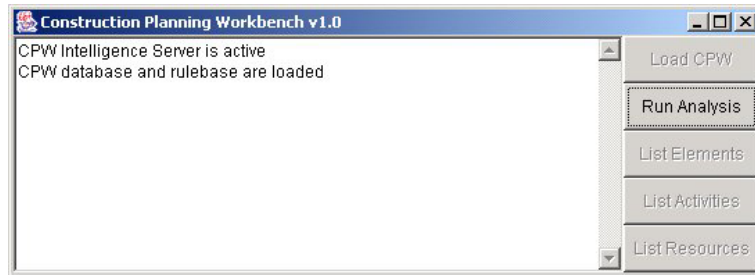


Figure 13 Loading rule base and connecting to the ODBC data source

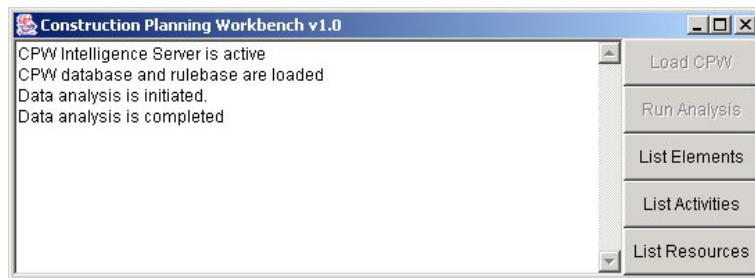


Figure 14 Generating construction activities, resources and job logic

A list of building elements, construction activities and required resources can be obtained after the completion of the data analysis as shown in Figure 15, Figure 16 and Figure 17.

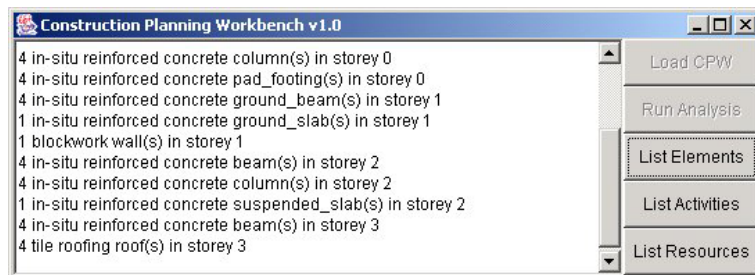


Figure 15 List of building elements

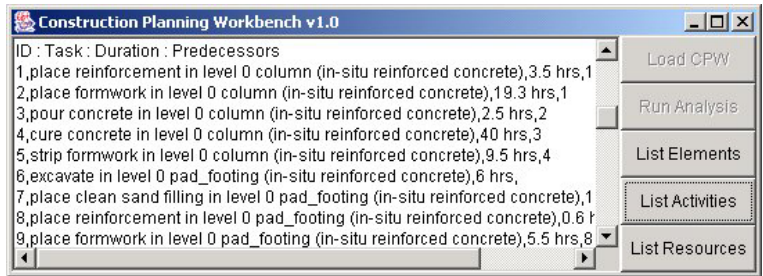


Figure 16 List of construction activities and their predecessors

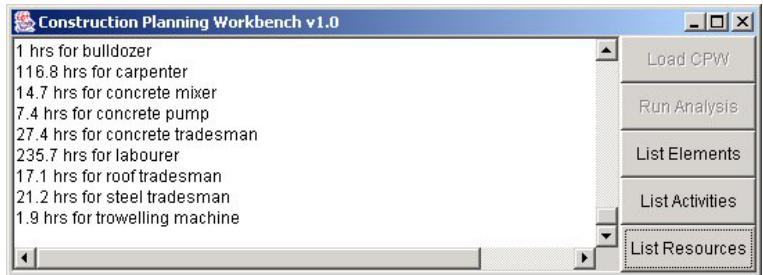


Figure 17 List of required equipment and human resources

Use of Microsoft Project

The result of the data analysis from CPW PINS can be imported into Microsoft Project by opening the same ODBC data source used in CPW PINS. The **File > Open > ODBC** menu is used to open an ODBC data source in MS Project

Pressing the "OK" button in the "Select Data Source" window (shown in Figure 18) activates the MS Project **Import Wizard** (see Figure 19).

The Import Wizard is a helpful tool for transferring project data between Microsoft Office Project and other programs. It uses import maps, which is a set of instructions that maps out for Project exactly what types of data are to be imported, in what order, and their field names in the destination format.

Figures from 18 to 22 illustrate the various steps in importing the database table "MSPri_Tasks" from the ODBC data source "cpw_store".

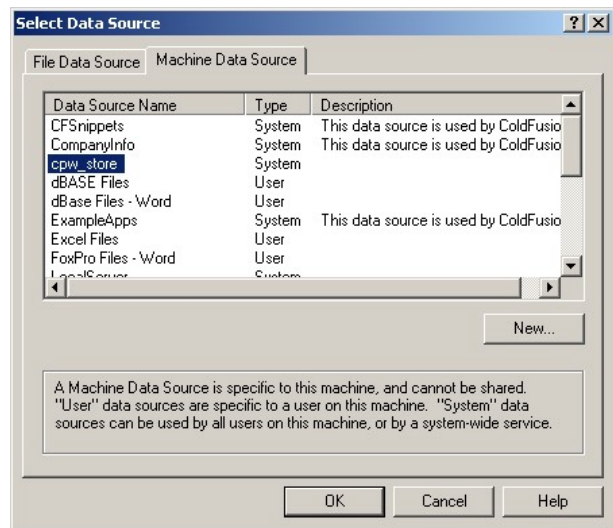


Figure 18 Opening an ODBC data source in MS Project

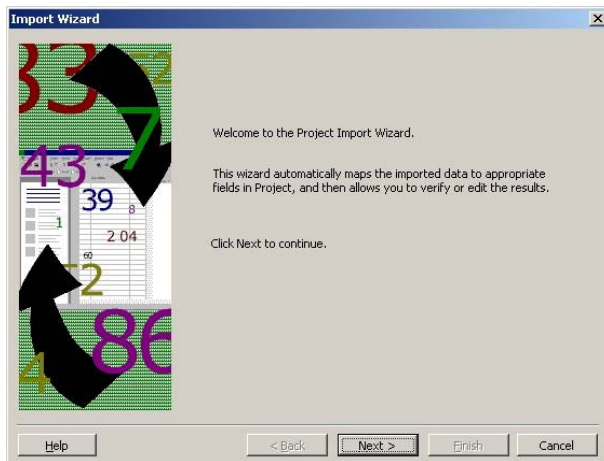


Figure 19 MS Project Import Wizard

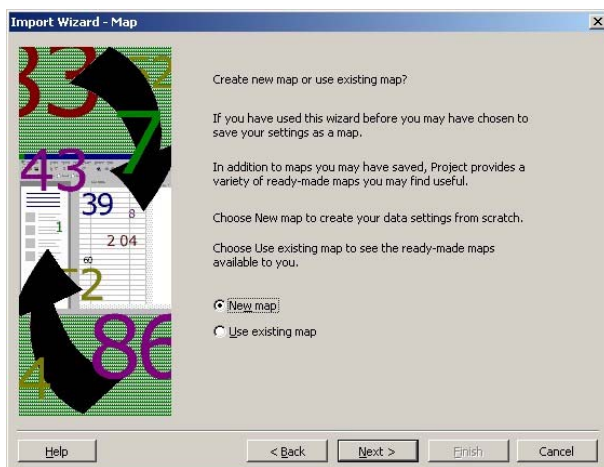


Figure 20 Creating a new data mapping

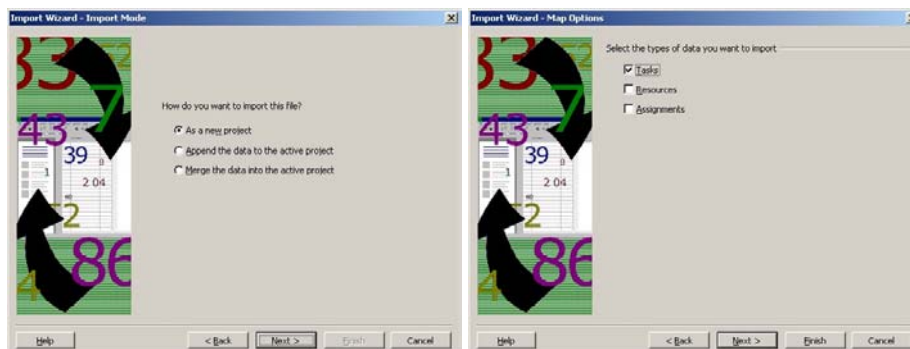


Figure 21 Importing task information into a new project

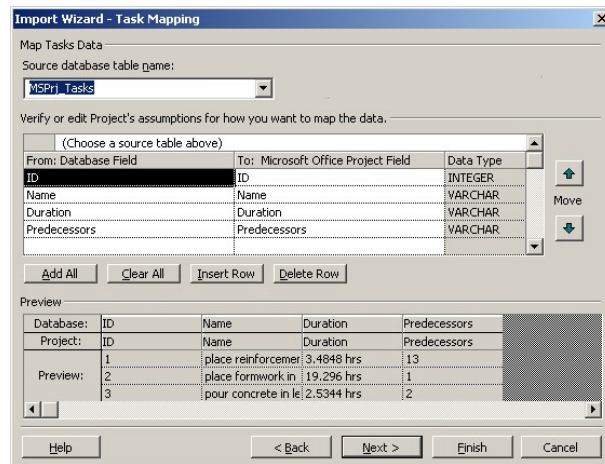


Figure 22 Data mapping for the database table “MSPrj_Tasks”

IFC to VRML converter

The use of Common Point as a tool for the generation of a 4D model implies importing a VRML (Virtual Reality Modelling Language) file for the visualization of the building and its construction as it evolves in time.

Having the project described using the IFC (Industry Foundation Classes), the generation of a VRML file with the information stored in an IFC file is needed.

Hence, a tool was created to convert the relevant information for the visualization, from IFC to VRML. This application has been written in JAVA and is composed of 3 packages corresponding to the different phases in the information flow: Ifc2x package, VRML and driver package.

In order to store the information contained in the IFC file, EDM Database was used. This object-oriented database allows importing IFC files with their schema describing the structure of the model. The schema used here is the ifc2x one.

Then a JAVA program makes a link to this database to extract the information needed for the generation of the VRML file. This information is then computed and a VRML file is created. Figure 23 shows this information flow from the IFC file to the creation of the VRML one.

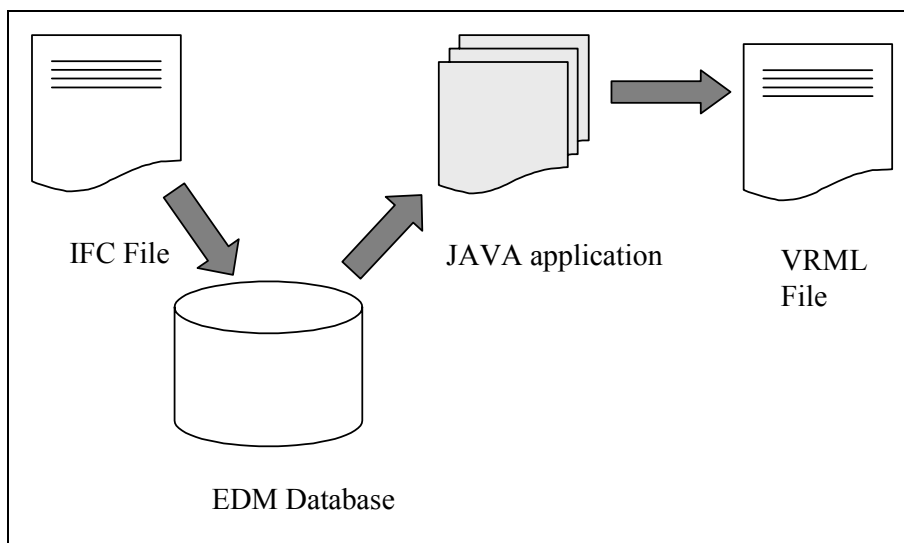


Figure 23 Information flow for the generation of a VRML file from an IFC file

The JAVA application is thus composed of three packages:

- A driver package, for the user to choose the database in which the IFC model is stored and open it
- A VRML package that organizes which data are needed for the generation of the 3D visualization and writes them in the VRML file
- An ifc2x package, that gets the information from the database and feeds it to the VRML package

Driver Package

The driver package contains the main method of the program. It creates a user interface (UI) as shown in Figure 24, that get the database location and name, its password, the name of the IFC model and the repository in which it is, and then the location and name for the VRML file.

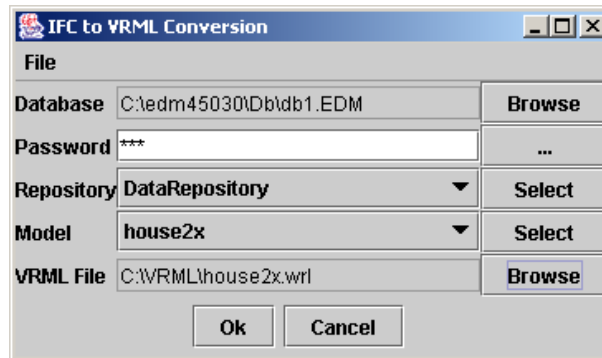


Figure 24 User interface for IFC to VRML conversion

Once the user enters all these fields, the program opens the database specified and gets the instance for the connection. It then calls the VRML and ifc2x packages for the extraction and computing of the information.

VRML package

The VRML package is the one that creates the VRML file. The 3D world is described in this file according to the VRML standard format and the information from the IFC file. The first line required in a VRML file is “#VRML V2.0 utf8” that allows the VRML browser to recognize the file as being VRML code and thus parses it correctly.

The objects in a VRML file are called nodes and are arranged hierarchically in order to affect one another in different manners. There are basically three types of nodes:

Shape nodes, which describe the geometry and appearance

Property nodes, which modify the geometry

Grouping nodes, which allow groups of objects to be modified as one object

Since the IFC data have a hierarchy between the different parts of a project, this hierarchy was respected through the grouping nodes in VRML. Hence groups were defined depending on how many sites were in the project, how many buildings in each site, how many stories in each building and elements on these stories.

Then in order to describe the elements within each group the shape nodes were used. These nodes describe the geometry of the element (box, sphere, cone...) as well as its appearance (colour, shininess, transparency...). The geometry characteristics (type of object, size, coordinates...) of each structural element of the project were given by calling geometry methods from the ifc2x package.

As described previously, Common Point does not handle all the geometry description that VRML does. Thus some modifications had to be done before writing the VRML file. For example, even if coordinates of the vertices of an element can be given in a local coordinate system and then transformed in the global one in VRML code, Common Point requires them

to be given directly in the global coordinates system. Hence methods in this package do the transformation first and then give the points in the global coordinate system. Moreover, some geometry properties are not either handled such as “Extrusion”, which takes a base of a solid, a direction and length of extrusion and thus describes the whole object. This would have been useful as IFC has the same representation, but in this case also, the calculation of the coordinates of the edges had to be calculated and then written in the VRML file.

After the geometry, the appearance of the objects had then to be described. The appearance is to render the object as wanted in the visualization window. Hence parameters differ depending on the colour and the aspect the material has, more or less shiny, transparent... At this stage, we have decided that all the elements constituting the building would have the same appearance in order to simplify the code.

Given the hierarchy between elements, and the geometrical and appearance properties of each element, the file could then be written according to the VRML code.

ifc2x package

The ifc2x package is the link between the driver package and the VRML one. Hence, it reaches the information contained in the ifc2x model, from the database and then gives it to the VRML package for further computation.

This package is constituted of many classes that describe entities as those defined in the IFC2x schema. Hence each class represents an entity and has the same attributes as in the IFC schema. Thanks to that, it is possible to follow the way entities are described and thus reach all the relevant information for the application. As an example, it is possible to get the instance of a slab as described in the model, and gets its attributes such as its geometry, location in global coordinate system, material ... All of this is got from an initial instance and following the structure to get the other ones that lead to the relevant data needed for the problem.

It is possible to get the information contained in an IFC file and writes them in a VRML file through the communication between those 3 packages.

This VRML converter supports the conversion of the structural elements of the building: walls, slabs, beams and columns. Not all the geometry is supported at present, only the most common ones (bounding box, extruded areas, clippings), which faces can be described as polygons. Hence, circles and curves are not yet supported as Common Point does not handle them, but approximating them by segments of lines still can represent them.

CONSTRUCTION PLANNING WORKBENCH: BENEFITS AND ADOPTION

Data collection

This section deals with the views of individual practitioners elicited from the two industry partners described in Section 1. The study is qualitative and of a consultative nature.

Study: views from industry

Semi-structured interviews were conducted with 11 key design and construction professionals and their attitudes to the use of product modelling elicited. Interviewees occupied various roles within their organisations and had different levels of planning experience (and can be identified as 1 to 11 in Figure 28).

Research approach and method

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

The study assessed participants' responses to concepts of 4D CAD, nD and product modelling. Fieldwork was undertaken with planning professionals from partner organizations, and results were documented 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). 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 from 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. Sorting is possible in a number of different ways and in a number of different arrangements, as described further below.

Figure 25 Model for interview analysis (Seidel, 1988) shows a model for interview analysis and describes the *iterative* process of data analysis and interpretation adopted in this study. The first step involved Importing and numbering files, followed by coding files, searching for segments, and finally discovering 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 will now be discussed.

The Ethnograph® was used for content analysis and to code text files. Once interviews were transcribed, various emergent themes were identified. Table 1, 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 full process is explained later in the 'Findings' section.

The initial texts, coded in the Ethnograph, were 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

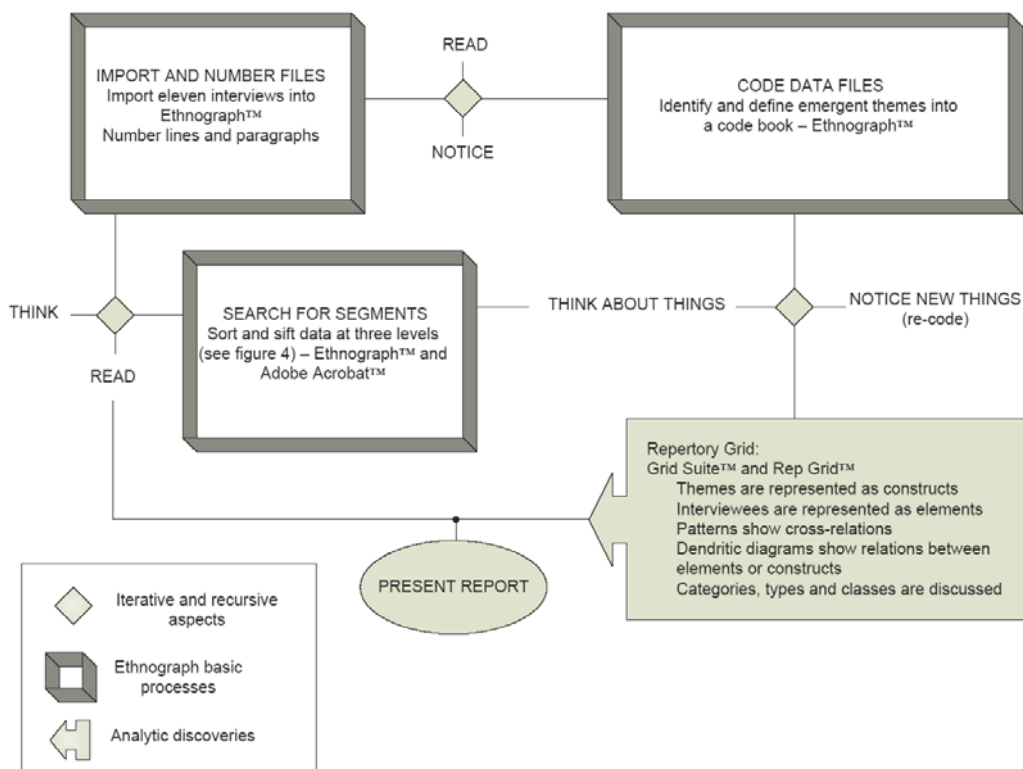


Figure 25 Model for interview analysis (Seidel, 1998)

At the discoveries stage (see figure 25), 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 analysis. 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 all interviews, and includes all participants and the themes discovered.

Interviews

Interviews were structured in the following six main sections:

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

Interviews were recorded using digital mini-disks and then transcribed into MS Word™. Speech segments were identified and tracks were marked to facilitate transcription. Once transcriptions were saved in a desktop computer, access to data was restricted only being accessible to the chief and co-investigators. Recordings of interviews were then destroyed and the transcripts rendered anonymous. The procedures for ensuring confidentiality and anonymity are recommended practice and requisites of University's Ethics Committee.

Transcribed interview data were imported into the 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 26). The code book also summarises the segments identified from the initial interview schedule (level 2 in Figure 26) and key words were then assigned to textual segments (level 3 in Figure 26). Once all transcriptions were coded, comparative sorting occurred. It was then possible to identify a series of “common underlying themes” resulting from the interviews.

In the context of this study, “themes” represent issues of concern voiced by the interviewees. The activities that identified these themes are shown in Figure 26. 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.

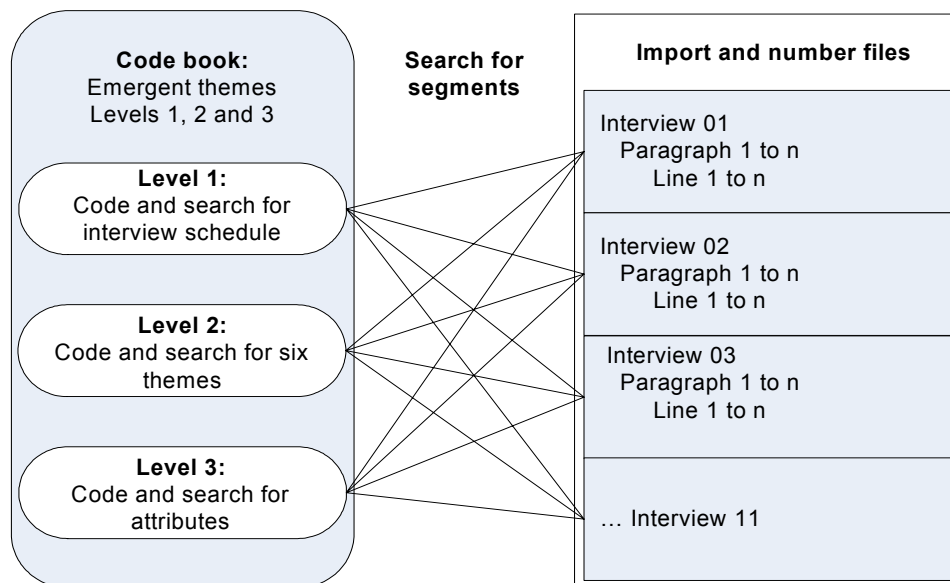


Figure 26 Code book and search for themes

Themes identified in the interviews include:

- 2D CAD (Theme 2 [T2])
- 3D CAD building documentation (T3)
- VR to assist communication with clients (T4)
- VR to assist communication with other professionals (T5)
- Client driven innovation (T6)
- Industry driven innovation (T7)
- Developed by consultants (T8)

- Developed in-house (T9)
- Feasible for use now (T10)
- Feasible for use later (T11)
- To be applied in many projects (T12)
- To be applied in a single project (T13)

T4 and T5 are supported by the findings of Whyte (2001; p101) who found that VR was used for a range of tasks to assist interactions with non-professionals versus the communication with other AEC professionals.

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. For example, some participants view the use of 3D CAD as a tool to improve communication with construction professionals whereas others see it as a medium to assist communication with clients.

T8 and T9 relate to the uptake of software, and to the tensions between consultants and contractors. The latter see themselves as close "followers", where *data models are to be created by a third party*, or by consultants (T8), and where *data models are created by contractors* (T9).

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. *To be applied in many projects* has an impact on many project, (T12), and *to be applied in a single project* impacts on single projects (T13). These views relate to whether implementation occurs throughout an organisation, or only 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.

Content analysis

The initial common themes in the interview data were 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*. Clusters were categorised as: *Personal, Case Study, Visualisation, Innovation, Barriers* and *Benefits* (see Figure 27).

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 that were identified and underlined.



Figure 27 Emergent clusters at level two

Researcher's comments and notes were added and summaries produced (including comments and underlined text) resulting in a 30 page review and interview summary. Summaries were then sorted in several ways for further scrutiny and interpretation, including:

- Sort by theme
- Sort by author
- Sort by participant
- Sort by keyword
- Sort by comment
- Sort by date

Some of the key quotes extracted from the 'sorting' procedure are provided in the next section.

Results

Highlights from the interviews provide a rich insight into relevant issues, and pertinent samples are provided below. Full interview relational grids are provided under the sub-heading "Grid representation".

With respect to who drove 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, 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 which enhance the work that we do and add value then we will always be looking to use them, but most times the client will definitely drive it"* [Contractor: Participant_07].

If innovation comes from within the AEC industry, who is the innovator and who provides IT expertise? A view commonly held by various contractor interviewees was that design consultants provide the IT "muscle". However, design consultants disagreed and emphasised that their documentation should be compatible with the systems contractors work with, for example, *"But to get value out of something like this, it has to be across the process. Sometimes we are only involved at 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"* [Design Consultant: Participant_02].

The value to contractors of using 4D modelling is to enable them to obtain a 'basic timeline', so reducing the amount of time and effort needed to prepare a construction program. These systems provide an *activity list* which covers all the objects in the model.

Another quote about the value contractors attached to 4D and nD modelling is that, "...to obtain value out of this is not easy. They are more likely to use it at conceptual level with consultants as a first cut schedule and take it from there to suit ...intended methods of working" [Contractor: Participant_01].

As contractors, Participant_1 and Participant_5 regarded themselves as temporary participants in the design and construction processes. For them it was "the client" who might 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 time line"
- "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 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™ 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)"* [Consultant: Participant_02].

Following this, Participant_02 noted that the concept of object models had taken some time to evolve but now seems to be working well. They also observed that, at this point in time, they find value in exporting drawings and components into spreadsheets which are then

used for estimates and updates, and in many cases are sent to sub-contractors and suppliers in this format.

Grid representation

In this study, repertory grids have been used to present 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. More information about repertory grids can be found in Fransella and Bannister (1977), and Kelly (1955). A good introduction to the technique can be found in the work of Stewart (1980).

Figure 28 synthesises all 11 interviewees and presents data showing relationships between participants and interview themes. The full grid shows both respondents and themes. The cluster patterns show links between bipolar themes and respondents.

Dendritic (or 'tree') diagrams may be used to present links between elements. The dendritic diagrams shown on the right hand side of Figure 28 indicate relationships between participants and themes. They show the level of agreement between interviewees (e.g. individual matches at 100%, 90%, 80% and so on). Numbers 1 to 11 identify the interview participants and linkages that are established by showing key characteristics (or "attributes") identified in the previous section. The attributes are plotted as "bipolar" constructs and each respondent is identified either to one side or the other of the *bipolar differential* (also known as semantic differential).

A strong linkage (e.g. 80%) indicates commonalities on views or attitudes amongst the respondents. Figure 28 indicates links at 59% and above. These links are based on proximities and tendencies identified during interview analyses. From Figure 28, three clusters can be identified:

- Cluster one: Participant_11 and Participant_02
- Cluster two: Participants_01, 03, 05, 07 & 06
- Cluster three: Participants_08, 09 and 04.

It is worth noting that participant 10, with a linkage of 60% to participant 04, has the weakest link with the rest of the group. Clusters can be classified as follows:

- Cluster one corresponds to participants with *strategic views*.
- Cluster two corresponds to participants with *organisational views*.
- Cluster three corresponds to participants with *project views*.

Figure 28 allows *clusters* identified by *colour patterns*. These are established between participants (1 to 11) and the themes they discussed (i.e. the relationship between bipolar constructs). The clusters in the left-hand column are light in colour whilst the right-hand column is dark. Colour blocks in the matrix indicate whether a participant relates more to the light column or to the darker column. Left and right columns represent extremes of the same concept – a bipolar construct [see Fransella and Bannister (1977) and Stewart, (1980)]. Grid clusters assist in identifying links between respondents (vertical columns) and themes (horizontal columns).

Grid results for the study show matrix clusters and dendritic diagrams (see Figure 28). Matrix clusters highlight areas of commonality across themes and participants. The dendritic diagrams show relationships between participants and between themes. To clarify these relationships, dendritic diagrams provide a graphical representation, showing 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 28.

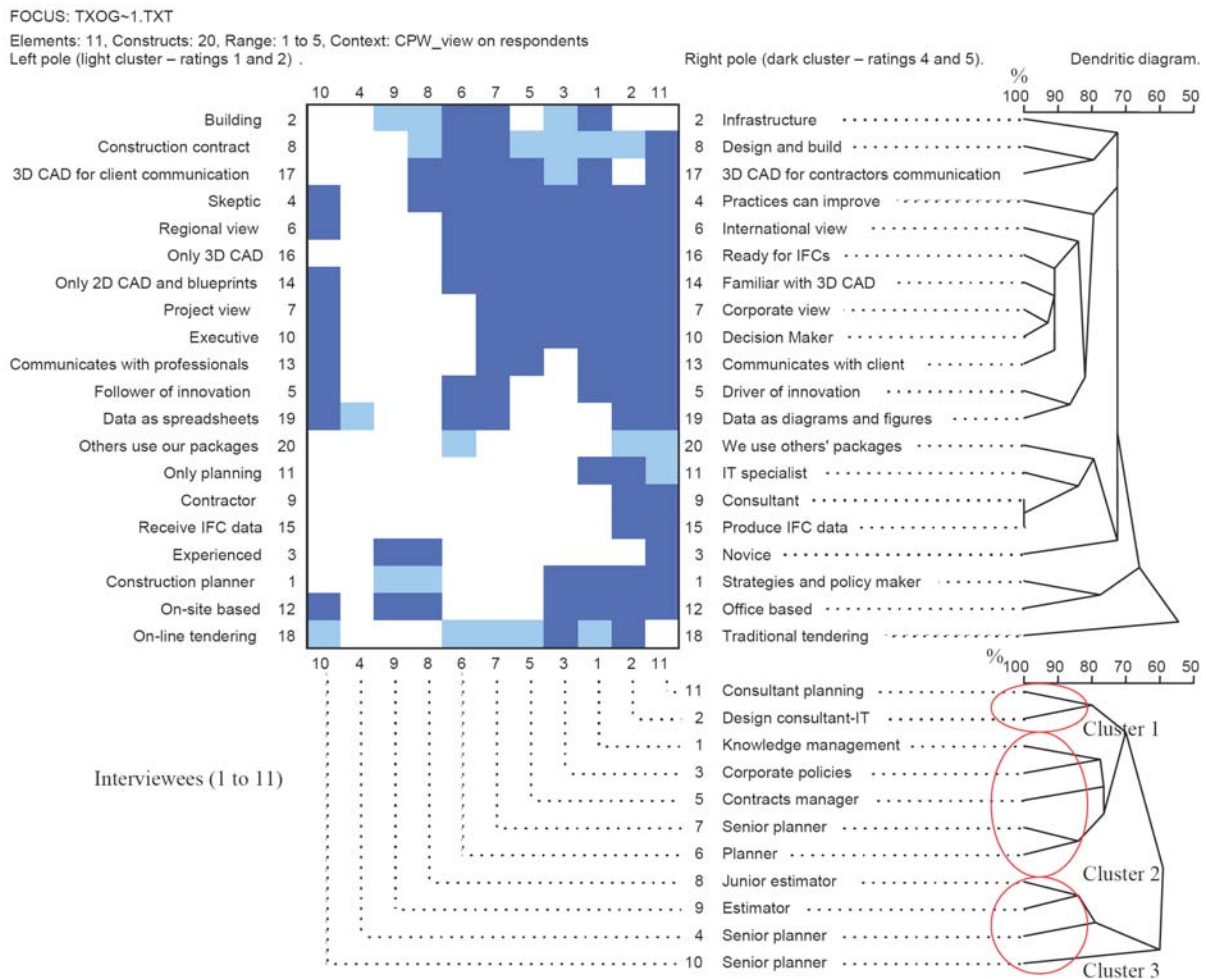


Figure 28 Themes at level three

The cluster grid (the chequered pattern in Figure 28) shows whether the interviewees relate to the right or left pole. For instance interviewees 2 and 11 (cluster 1) relate to the right pole. 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” represent a collection of similar views.

Figure 28 provides a detailed representation of the links between constructs (or themes at level three). For instance, it shows two constructs that match at 100%: Constructs [Contractor / Consultant] and [Receive IFC data / Produce IFC data]. 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 not prepared to generate models, including those from IFCs databases. However, the contractor certainly finds value in using them.

Other construct links correspond to at least 82%, and indicate a strong relationship. These include:

- [Corporate view / Project view] with [Decision Maker / Executive] merge at 86.0%

The proximity between the two previous constructs (at 86%) establishes a relationship between the views of individuals at various organizational levels, and their views on how technologies can be implemented.

- [Corporate view / Project view] with [Familiar with 3D CAD / Only 2D CAD] links at 82.0%

The proximity between the two constructs (at 82%) means that the views and policies to adopt 3D CAD come from top management decision-making.

Conversely the proximity between the two 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] links at 82.0%

The proximity between these constructs (at 82%) implies that, to achieve “product modelling” (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 how industry sees moves to incrementally embrace product modelling.[Consultant / Contractor] with [IT specialist / Only planning and scheduling] links at 100%

The similarity between these constructs (100%) may be interpreted as an expectation that consultants lead the implementation of product modelling efforts. On the other hand, consultants see themselves as being required to provide this service for no extra cost, and at this stage they see very little benefit from this. Consultants consider that the skills needed to create IFC files are not available yet. For this reason consultants also see opportunities for third party service providers (or research venues such as the CRC CI) to lead the development and implementation of product modelling.

Contractors see themselves as “interested followers” of the technology. However, 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 to clients.

“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.” [Contractor view: Participant_01].

Repertory grid constructs with strong linkages have been described above. Other bipolar constructs can be identified from Figure 28. For instance: [Practices can improve vs. sceptic] refers to the two extremes between optimism 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 show more willingness to change current practices (with values of 1 and 2) (see Figure 28).

Another example is that of the attribute [*Communication with client vs. communicates with other professionals*]. This relates to the use of 4D CAD and nD modelling as tools to improve communication, either with clients or with other professionals:“... *this is of great use to synthesise 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” [Consultant view: Participant_11].

The above corresponds with the observations of Whyte (2001; p101) who found that VR was 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. 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... 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” [Contractor view: Participant_07].

Discussion

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

However, results also show that participants 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, on-line shared CAD repositories and CAD integration with spreadsheets is seen as a “stepped” improvement. Another implication with intermittent results is that of motivating industry at all levels (from strategic to grassroots) and to actively engage in research and development (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 IFC’s). 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 SME’s.

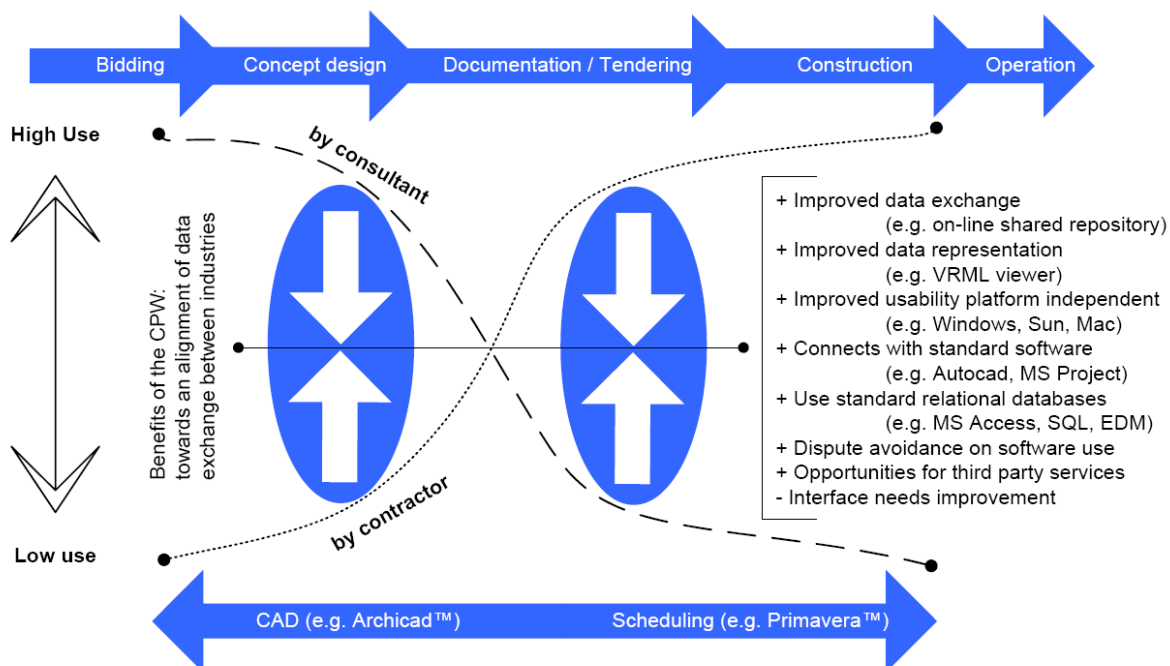


Figure 29 Software alignment

Results from object models can only be used as *first cut* solutions and need to be reviewed and refined. Results show that neither contractors nor consultants wish 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 could be specialist consultants or a governmental initiative. For the two industry partners, 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 IFC’s because there is not that much expertise out there. So you need to have a very special consultant to deal with.”* [Contractor view: Participant_05].

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 IFC’s might take up to a decade to be fully consolidated (if IFC’s were to become an industry standard). This finding is supported by Amor and Faraj (2001) and more recently by Dawood, et. al. (2003).

A more optimistic view of IFC’s, held by both contractors and consultants, is that the use of IFC’s is an opportunity to “align” the use of software and reduce power struggles associated with deciding who is going to use whose software. Results showed a consensus, i.e. that design consultants will always spend time and resources on CAD systems whereas contractors will invest in programming and scheduling packages. To the latter, the advantage of IFC’s is that they will provide a connecting device, as shown in Figure 29.

Other quotes relating to Figure 29 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 IFC’s have a practical use.” [Consultant view: Participant_02].

“... 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 IFC’s sits in here and we have a shared repository and we can bring those two together. That would be attractive to both.” [Consultant view: Participant_02].

“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”. [Consultant view: Participant_11].

“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.” [Contractor view: Participant_05]

Figure 29 summarises industry participants’ views of the main potential benefits of nD modelling. These include applying product modelling and industry standards for construction documentation. The main deliverable of this Construction Planning Workbench research project is an in-house software application that implements the principles of IFC’s, facilitating the integration of CAD tools and programming software. As construction projects progress through their lifecycle, the interest / application of consultants and contractors waxes and wanes in different cycles. 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, as shown in Figure 29.

Current applications and future developments, as viewed by the AEC industry, are mapped in this paper.

Conclusion

Qualitative data analysis was used to identify 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 views from industry 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 projects. Evidence showed a positive response to 3D design documentation.

There was consensus between the interviewees that the implementation of nD modelling technologies (such as IFC's) would be considerably eased if third parties produce 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 more important for small and medium enterprises (SME's). A way forward was proffered by one of the research participants, *"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."* [Contractor view: participant_08].

CONCLUSION AND RECOMMENDATIONS

This report shows that IFC data is a potential source of information in the generation of draft construction schedules. The report illustrates the feasibility of using logic programming to codify knowledge and trade practices in the construction industry. The use of logic programming, instead of other software development paradigms, allows the development of a flexible and expandable domain rule base.

The results obtained in this report are potentially useful in the development of practical and effective tools for generating draft construction schedules from 3D CAD models. The initial results of the CPW initiative can provide a framework for a practical approach to the partial automation of drafting construction schedules for full-scale projects.

One of the future goals is to capture industry knowledge and trade practices in construction planning and scheduling and thus maximising the benefits from this vast repository of knowledge and past experiences. Another useful extension to the project is to develop protocols and guidelines in order for CAD documents to be more amenable to automated data analysis that is required in planning automation such as CPW.

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