APPLICATION OF VISUALISATION TOOLS IN PROJECT MANAGEMENT IN CONSTRUCTION INDUSTRY: INNOVATION AND CHALLENGES

Ramesh Marasini1, John Dean2, Nashwan Dawood3
r.marasini@tees.ac.uk1, j.dean@tees.ac.uk2, n.n.dawood@tees.ac.uk3
Centre for Construction Innovation and Research, School of Science and Technology
University of Teesside, Tees Valley TS1 3BA.

ABSTRACT

The advancement of information technology has resulted in the development of new visualization and planning tools that offer major improvements when compared to the use of traditional planning tools such as Gantt charts and Critical Path Method. Despite their limited capability for planning and monitoring projects, these tools are still almost universally used by the construction industry. Two case studies managed using traditional techniques, one construction of an apartment block and other installation of a new high technology production facility in the Precast Concrete Industry have been reviewed in the paper from a viewpoint of how the application of new 4D (3D+time) and visual planning/simulation techniques would have improved the management and control of the projects. Widespread use of visualization and simulation techniques in the Aerospace and Car Industries is compared with the limited use in the Construction Industry. The paper examines the barriers to the introduction of the technology based on the experience gained from the presentation and demonstration of the visualization technology to six major construction companies operating in the UK construction industry and the means of breaking down the barriers to the implementation of the new IT innovation are discussed.

Key words: Innovation, IT Tools, Project Management, Visualization

1. INTRODUCTION

The advancement of information technology has resulted in the development of new visualisation and planning tools that offer major improvements. The outputs of traditional planning techniques are very difficult to communicate and validate as the complexity of the project increases. Despite their limited capability, these tools are still almost universally used by the construction industry. These tools don’t show the three dimensions of space and the fourth dimension of time, making it difficult to analyse and visualise construction sequences (Sheppard, 2004). The knowledge, skills and awareness of project planning is the key competency of planners which is difficult to communicate and pass on to the other stakeholders and as the project progresses significant gaps begin to occur in the understanding and comprehension of all planning issues by the other stakeholders(Gardiner and Ritchie, 1999). Furthermore, the planning and scheduling process is a multi-disciplinary team process. Being able to communicate the plan, at any stage of the project, is essential to ensure that a reliable and workable plan can be used by the project team and visual planning and simulation techniques such as 4D (3D product
model in CAD or Virtual Reality (VR) + time i.e. schedule) offer an easy means of communication. VR provides users with a medium to walkthrough the model and visualise or experiment with the model. If schedule information is linked, it allows the users to see the time phased status of the project in terms of the execution of the project thereby enabling the users to identify existing or potential problems before actual execution begins. 4D models have been expanded by increasing their functionalities by researchers such as Wang et al (2004) and several prototype and commercial developments have been reported in the literature (Fischer; Construction.com; Heesom and Mahdjoubi, 2004). In this paper, the aim is to explore the benefits of using the visualisation technologies and identify challenges for its adoption by the industry.

Two case studies managed using traditional techniques, one construction of an apartment block and other installation of a new high technology production facility in the Precast Concrete Industry have been reviewed in the paper from a viewpoint of how the application of new 4D and visual planning/simulation techniques would have improved the management and control of the project. The collaborative culture of involving all the project partners in the planning process including the client embedded in the 4D concept is considered alongside the performance improvement that would have been accrued by the use of the new technology. Despite the many advantages offered by using advanced planning techniques such as 4D, as developed from the case studies and cases evaluated by other researchers, new visualisation technology is not widely used by the construction industry.

The paper examines the barriers to the introduction of the technology based on the experience gained from the presentation and the demonstrating of the visualisation technology to six major companies operating in the UK construction industry. The widespread use of visualisation and simulation techniques in the Aerospace and Car Industries is compared with the limited use in the Construction Industry. Recent research activity carried out by the authors into the Key Performance Indicators improved by the use of visualisation and spatial optimisation is outlined as a means of breaking down the barriers to the implementation of the new IT innovation in project management.

2. 4D AS A VISUAL PLANNING TECHNIQUE

4D combines 3D CAD model and schedule information and produces visual animations of the construction sequences. This plays a key role in identifying scheduling conflicts, safety issues and space utilisation at any time during the construction process. Space plays a critical role in situations where the construction area is confined or is limited depending upon the location of the site, construction technology, access routes etc. Details of 4D research and application, discussed by Martin Fischer, can be found in Stanford University web pages. Sheppard (2004) highlights some case studies of different 4D technologies in construction projects and how its benefits were realised. Figure 1 shows a methodology of a 4D software developed in Centre for Construction Innovation and Research (CCIR), University of Teesside that visualises construction product and processes in CAD and VR environment linking 3D CAD and project schedule through a central database and
the 4D model is organised using standard classification systems such as Uniclass (Crawford et al 1997).

Figure 1 Overview of 4D Methodology

Figure 2 4D Visualization with activity progress

Figure 3 Photorealistic image of a Gas Receiving Facility

Figure 2 shows how planned and actual process information can be visualised and figure 3 shows an example of photorealistic image of a gas receiving facility modelled using 4D technology. Most of the 4D software either available commercially as of-the-self package or on consultancy basis use similar building blocks, however, may differ in terms of modelling CAD, linkages with plan or both. The initial advantage of using 4D is that for any construction project it ensures that a proper 3D CAD model and a schedule is available. Once a 4D model is developed, several what-if scenarios can be evaluated visually by the planners thereby identifying sequence conflicts or space clashes if space usage is modelled.

Visual planning techniques can realise many benefits on construction projects. Some of the benefits will be: major saving in waste, improved site productivity, avoidance of cost overruns, accurate planning decisions through rehearsing the construction process, identification of resource conflicts and assessment of safety issues, communication of project processes to all project parties (in particular senior managers) including accurate workface instructions – to reduce execution errors and utilization of advanced technologies and algorithms in making decisions.

3. CULTURE OF CONSTRUCTION VS. AUTOMOTIVE AND AEROSPACE INDUSTRIES

The Construction Industry lags behind the car and aerospace industries in the uptake of information technology including implementation of visualization and simulation to improve their business processes. A report by Green et al [8],
discussing the managerial practices in the construction and aerospace industry, highlights that construction firms frequently compete on cost efficiency rather than the innovation and technical expertise. There is no doubt that the case study projects would have benefited from the seamless integration of photo realistic and 3D modelling using a combination of 3D AutoCAD and Virtual Reality Modelling language (VRML) coupled with critical space analysis and optimization software. Gould (1998) outlined the extent of visualisation in the Car Industry ranging from concept, design, engineering to scientific visualisation of data for crash analysis and cited the comment of a senior designer at the Chrysler Technical Centre as “Visualization is an intricate part of our day-to-day process because our data goes through various stages of scrutinization”. This comment embodies the attitudes prevailing in the car and aerospace industries where it is now fundamental part of the culture associated with these industries. Karl Mecklenburg (2001) outlined the benefits of seamless integration between plant layout and discrete event simulation (DES) in order to enable the virtual factory concept to be realized. One application in car manufacturing is the application of 4D Navigator of Dassault Systemes by BMW as described by Grandl (2001) in experimental vehicle build to verify both product and process eliminating many tasks during the preparation phase. Examples of the problems identified in this experiment were: collision with floor assembly, access with screwdriver critical, torque information missing, assembly concept not verified, hole missing etc. The analysis of the problems encountered in two case studies are presented below which will highlight the differences.

4. CASE STUDY 1: PRECAST CONCRETE PRODUCTION OPERATIONS

Introduction
The project involved the transition of Wet Cast Paving manufacturing from a manual partially mechanised operation into a fully automated flexible production system. The manual processes involved are illustrated in Figure 4. The project included the building a new factory extension and equipping the factory with high tech production processes in a lean and flexible manner utilising vision enabled robot technology, Asi-safe, SCADA and Device networks automated pallet shrink wrapping and strapping equipment linked with the conveyor system and paving mould carrier cassettes, project cost was £2.6m. Flexible automation utilising linear motion devices was initiated using encapsulated read/write Radio Frequency Identification (RFID) Tags.

The project involved the use of technology developed for the car and aerospace industries including the cultural concepts of single minute exchange of dies developed originally by Shigeo Shingo (1995) for the Toyota car plant. The single minute changeover concept was enhanced in this application to four seconds. Elimination of Non Value Adding Waste (NWAW) as outlined by Mather (1988) was embodied as a main lean feature in the design concepts used to develop the final specification detail for the contract. Vision enabled robots are used in the aerospace industry for the precision fitting of components by robots. Car and Aerospace industry concepts were embodied operational techniques to be employed in the design of the project but not in the execution of the project where traditional project management tools including MS Project and an Excel based cost
control system were used by the project manager. The client produced a detailed specification for the equipment installation and the building and the project was organised as shown in the organisation chart shown in Figure 5.

![Manual Processes to be replaced](image)

**Figure 4** Manual Processes to be replaced

![Precast Transition Project-Organisation](image)

**Figure 5** Precast Transition Project-Organisation

![Some examples of the automation introduced](image)

**Figure 6** Some examples of the automation introduced

The client used MS Project and managed all elements of the project with the exception of responsibilities allocated to the ‘prime contractor’ for the robot
systems, systems integration, mechanical handling and the electrical installation. A car industry robot supplier was chosen to be the prime contractor and a fixed price contract was negotiated including the prime contractor taking control of the project management responsibilities. The pictures presented in Figure 6 illustrate the nature of the transition that was accomplished by the completion of the project.

Post Project Review findings
The cost overrun on the whole project was 3.8% which was well within the performance guidelines set by the clients’ parent company, of ±5% of original capital submission cost. The project was planned to be completed to commissioning stage in 12 months unfortunately the project overrun was three months. This was caused by the lack of information transparency by the prime contractor and the incapability of the electrical installation and systems integration sub-contractor to apply sufficient resources to recover from an underestimation of the work content. The prime contractor had failed to manage the sub-contractor and had not appreciated the level of work content involved. Extensive client involvement brought the project back on course and prime contractor was forced to employ additional internal resources since the sub-contractor became virtually insolvent.

Since all of the drawings were in two dimensional format a key dimensional error relating to the height of mould carrier on a conveyor relative the concrete filling chute from the mixer was not noted until the final installation of the equipment. With two separate contractors involved the client was forced to modify the mixer support structure to overcome the problem, this contributed to the cost overrun. Despite regular meetings and corrective action requirement the key performance indicator information was not available in time for effective corrective action. For example planned activity hit rate was at times a month late and a lack of transparency was evident.

The accuracy of workface information was suspect at times and there was evidence of re-work and changes/modifications necessary because of incorrect and out of date information being given to the workface installation trades especially relevant to the electrical system development where it was apparent that a significant amount of systems design took place during the installation or execution phase. This should have been completed ahead of the execution process, however the project included much new innovation, which accounted for some of the modifications and it won a major industry award for innovation from the British Precast Concrete Federation, UK.

Improvements that would have been achieved using visualization tools
The illustrations in figures 1, 2 and 3 give a brief overview of a 4D (3D+Time) advanced visual planning/simulation systems that could have been used to control the project. Through the use of 4D visualisation model, the following problems would have been avoided:

- The dimensional clash issue relating to height of mould carrier relative to the concrete filling chute and the associated cost and time associated with the modification would have been avoided.
- The limitation in capacity of electrical subcontractor to progress with the electrical installation and system would have been obvious either during the
rehearsal phase or at an early stage during the execution phase to enable corrective action.

- The availability of real time KPI information via the web in-turn enables remote project meetings using photorealistic images of progress with embedded activity completion lists would have been very beneficial in the case study project and it would have resulted in any corrective action required during the meeting review process to be taken in a timely manner.
- Transparency of information is inherent in the 4D visualisation process and the project teams must accept this for the benefits to be accrued.
- Without an overall project database with internet access meant excessive client time was needed to ensure that the target delivery dates were achieved. With the aggregate feed and mixing plant built in Northern Ireland and the shrink wrapping/strapping equipment from Italy, internet based remote project meetings would have been very useful.
- The cost overrun was approximately £100k and most of this cost overrun could have been avoided through the use of 4D visual planning. A project management cost budget of £30k was included already in the overall project budget. It is estimated that an additional £30k would have been required to fund the additional planning activities involved in the application of 4D technology, however, when viewed in simple financial terms this would have represented a payback in less than four months. In addition to the cost overrun the project was three months late which represented a three months loss in the savings scheduled to be accrued from the project which were planned to be £850k per year. The loss of savings amounted to £283k, when viewed in these terms the payback reduces to less than one month.

5. CASE STUDY 2: CONSTRUCTION OF A 30 FLAT APARTMENT

Introduction
This project (Figure 7) considered the construction of an apartment block with thirty units on three levels and two sets of communal stairs servicing fifteen units each. The building was built utilizing traditional construction methods (suspended beam and block) with precast flooring members and precast stairs. The initial contract was to build the shell of the apartment block. Unfortunately, after building the shell had commenced, the construction company were awarded the contract for fitting out and the external works contract including the car park and drainage. The project completion was delayed by two months. The management team argued that the project would have been completed on time if all elements of the contract had been awarded at the outset so that effective planning could be undertaken.

Figure 7: Case study 2 project with 4D Visualization
There was only one access to the site. With roads at either end of the site and a brick wall and fencing to each side, the site was enclosed to avoid off-loading issues with local residents and road safety problems. Vehicles were effectively forced to enter the site with only one entrance for off-loading.

Problems Encountered

Statutory services became an issue because gas and water connections were only available in one major road nearby parallel to the site and electricity required connection from the opposite end of the site. The result was that a trench running the whole length of the site was necessary. The end result was that co-ordination of deliveries became extremely difficult and the original intention of using fork lift trucks for off loading vehicles had to be abandoned because of access issues. A crane had to be leased and mounted on a concrete pad for stability purposes. The crane serviced all erection and offloading on the site. Critical space analysis embodied in 4D would have assisted significantly here.

Redesign of flooring units: The need to utilise a crane required the redesign of flooring units instead the planned use of 1200cm units it was necessary to use 600cm units because of weight restrictions. Fortunately, the supplier was able to supply the units required in time. The contract for the external works was only awarded after the building activity had commenced and it was necessary to redesign the drainage system to avoid the roots of the three large trees. The crane required banksman for slinging and a crane operator. The crane costs and productivity issues were partially offset by reduced a fork lift truck costs.

Two dimensional drawings and the lack of adequate quality checks by the GRP Dormer window supplier meant that two different pitch roof structures had not been noticed by the supplier. Hence the GRP dormer windows were supplied for one Pitch only. The wrong dormer units had to be returned and new units manufactured, which extended the scheduled watertight time.

Improvements that would have been achieved using visualization tools

The architectural errors, problems with the statutory services, redesign of flooring units would simply have been detected using the 4D visualization tools. The high level of visual information from 3D model or photorealistic images would have prevented the problem with dormer windows and the inherent transparency of information and rehearsal involved in a client walkthrough would have prevented the sequence issues and improved the management of problems indicated above.

6. CHALLENGES TO THE INTRODUCTION OF THE TECHNOLOGY IN CONSTRUCTION

The 4D model developed at Teesside University [Figures 1, 2, 3] was demonstrated to six major AEC companies in UK and these demonstrations generated high interest among the contractors and appealed to the planners the most. Due to the lack of appreciation by the senior managers, many companies did not take up the project. The challenges, as highlighted in the discussion, are:

- Adversarial relationships in the procurement and execution processes. In 4D model use, client could be involved from the start and collaborative approach is seen as essential.
− **ICT Skills Shortage** – There are 3D skill shortages in the construction industry. Hence, traditional way of developing 2D drawings is continued by the industry.

− **Time available to tender** – The time between the release of tender documents to submission is relatively short and construction companies do not have sufficient time to develop 4D models since the process can take a few weeks.

− **Fear of transparency of information** – There is a key concern among construction companies that the client could use the information provided against the construction company since delays and errors would be visible to the client. The other kind of fear is the use of explicit information about the technical aspects of the operations which companies may not wish to share with others to protect their opportunities for obtaining future contracts.

− **Fragmented industry** – The industry is fragmented with many small subcontractors. In the UK 80% of the subcontractors have less than 20 personnel.

− **Resistance to change** – There is a reluctance to change working styles with a belief that the traditional approach still satisfies the job requirement.

### 7. INITIATIVES REQUIRED TO ENCOURAGE THE ADOPTION OF VISUAL PLANNING TECHNIQUES

The lack of adoption of the visual planning techniques such as 4D is evident in the construction industry. In order to enhance adoption and realize the benefits by the industry, initiatives from the government, professional bodies and main construction firms are required. Some examples are:

− **Identification of clear benefits of the application of visualization techniques**: There is a lack of industrial applications that have clearly justified and encouraged the application of 4D techniques. Currently the authors are conducting research, funded by a company developing and utilising 4D in construction projects on a consulting basis, to quantify the benefits of using 4D on construction projects. An analysis of case studies of three main construction projects in London and the results of 10 semi-structured interviews with the planners and managers involved in the execution of the projects use of 4D planning revealed that the factors that can be influenced or improved by the use of 4D planning include: time (85%), communication (73%), planning efficiency (70%), safety (68%), client satisfaction (63%), rework efficiency (63%), cost (50%), team performance (50%) and productivity (15%). The results show the percentage of respondents that ranked the factor as most important.

− **Push from the clients**: Large clients should include visual planning techniques as part of the project contract so that clients and construction companies will be in a “Win-Win” situation by minimising wastes during the construction process.

− **Training on the application of 3D** – Use of 3D models in the development initial brief is growing. Software like SketchUp™ (www.sketchup.com), Revit™ (AutoDesk, Inc) etc are helping Architects and Designers to start developing models in 3D and generating 2D drawings directly from the CAD applications as used in the aerospace and manufacturing sectors.

− **Issues with compatibility** – There are significant problems with the compatibility across the CAD software used in the construction industry. Initiatives like industry foundation classes (IFC’s) should be encouraged so that
CAD models can be exchanged easily without losing accuracy and reliability of
CAD models during the conversion processes.

– **Cost of the technology** - The current cost of 4D techniques are high compared
with other project management software. However, the commercial
development of 4D software application is growing and there is a need to
develop best practice examples.

8. CONCLUSION

The adoption of visual planning tools for project management is very slow despite
the fact that such techniques facilitate planners and stakeholders to visualise the
project execution process and identify problems that may occur before construction
takes place. Advancements in 4D CAD and virtual reality are capable of handling
complex models and can change the culture of the construction industry. Initiatives
are required to encourage the use of visualisation techniques are seen as essential
and researchers, developers and industry must work together to deliver affordable
solutions for the construction industry and lessons must be learned from the
benefits gained by automotive and aerospace industry.

9. REFERENCES

http://www.construction.com/NewsCenter/it/features/01-20010618.asp
Crawford, M., Cann, J. and O’Leary, R (1997). Uniclass (Unified classification for the
construction industry). *Royal Institute of British Architects Publications (RIBA)*,
Fischer, M., Stanford University, *4D CAD research*. Accessed on 15 May 06,
http://www.stanford.edu/group/4D/index.shtml
information management metamorphosis or technology going too far?.
25 May 06.
Grandl, R.(2001). Virtual process week in the experimental vehicle build at BMW
sectors: knowledge sharing between aerospace & construction. ICRC, University
of Reading.
181.
