VISCON: COMPUTER VISUALISATION SUPPORT FOR CONSTRUCTABILITY

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SUMMARY: *The construction industry has a reputation for low productivity, waste, low use of new technologies, and poor quality (Egan, 1998, Wakefield and Damrianant 1999). It is estimated that up to 30% of construction is rework, and recognised that site teams spend too much time and effort making designs work in practice (Egan 1998). The aim of the research project presented in this paper was to develop a visualisation and communication environment that would assist design teams in communicating design details that may be problematic for construction teams. The investigation was based on the need for a tool that facilitates the communication of detailed design information. A survey was used as the method for collecting data to establish a general industry-wide perspective on the role of visualisation in Constructability. In this research project, prototyping was used as an approach to demonstrate the use of different types of computer visualisation as a communication medium to exchange design information during the construction stage. A framework has been developed for the flow of information related to Constructability between design and construction teams during the construction stage of a facility.*

KEYWORD: *visualisation, animation, VRML, constructability*

1. INTRODUCTION

During the construction process, subcontractors face a number of problems, one of which is interpreting intricate design details, they sometimes spend too much time and effort trying to understand the design intent and may need help from the site team (Bennet, 1985). The site management team may, in turn, need to contact the designer to clarify these details and how they can be implemented. This may require additional drawings to be produced. It is estimated that nearly 45% of all quality problems occurring on construction sites are due to inadequate project information (Snook, 1995).

Computer visualisation has become the field that designers are currently seeking to exploit as a new technology to cope with a rapidly changing construction industry (Newton, 1998). Project information visualisation is not only important at the design stage but is also becoming increasingly important at the construction stage. It can be a valuable tool for enhancing existing systems with respect to construction sequence, equipment access, completed work and assembling difficulty components (Alshawi and Underwood, 1999). In addition to this, visualisation augmented with good communication facilities could create the necessary links between site and design teams to collaboratively solve Constructability problems that may arise during construction (Construct IT, 1995).

In view of the above, there is the need for a visualisation system that is capable of providing an effective tool for communicating graphical Constructability information between design and construction teams. It is this need that this research addressed; the results are presented in this paper.

2. RELATED WORK

A number of researchers have developed computerised systems for Constructability improvement. These systems can be divided into three types (Navon et al, 2000);

The first type uses a database of known Constructability problems, or examples of good practice. This includes a system developed for the US Army Corps of Engineers (CLL, 1998) which contains experience accumulated from a large number of projects. This approach lists a number of potential problems that engineers should be aware of and suggests solutions to them. Although this system is useful, it ignores the fact that in many cases the lack of awareness itself results in Constructability problems.

The second type integrates Constructability knowledge within an automated design system, such as the system developed by Alshawi and Underwood (Alshawi and Underwood, 1996). The system developed deals with exterior cladding and lining taking into account the elements available, installation sequences, building codes, etc. The system can also recommend changes in building measurements to reduce the need for manual completions. The system generally offers concepts that prevent specific Constructability problems but it does not diagnose a given design.

The third type analyses an existing design from an execution viewpoint using a system that examines the design and informs the engineer of any Constructability problems (Fischer, 1993). The problems that this system deals with are those related to the dimensions of the building elements that do not correspond to the standard form-work available. Another application that identifies clashes between services systems (electrical, air-conditioning ducts or water supply, etc.) using 3-D models was developed by Kuprenas et al. (1993). Navon et al. (2000) criticised this application, stating that it may mistakenly identify joints or junctions as a clash between two elements as the application uses separate entities for each element (e.g. electrical lines, ducts, water pipes, etc.).

3. CONSTRUCTION VIEWS AND PERSPECTIVES

An industry survey has been conducted to establish current practice in the use of visualisation tools within the construction industry. A four-page questionnaire was sent to 100 organisations randomly selected from the top 100 UK construction consultants and contractors based on turnover (New Civil Engineer, 1999). The survey questionnaire was designed to investigate the use of computer communication and visualisation during the construction stage of medium to high-rise buildings. It focused on the use of these technologies within the organisation and when communicating with other participants in the design and construction of buildings. The other purpose was to investigate Constructability problems that might arise during construction.

The analysis of the results shows that the use of computer visualisation and communication is very low. The most common methods and tools used for communication between design and site teams were traditional methods and tools such as 2-D drawings, face-to-face meetings, written statements, telephone and fax. They are accustomed to these methods and tools and find them easy to use. These methods and tools are not adequate and fast enough in communicating requests for information. The respondents thought that delays in obtaining information and the lack of adequate information during the construction process might contribute up to 30% of the total delay in a project.

The most common use of computer communication is e-mail especially by site teams to communicate with their head office, subcontractors, and other members of the supply chain. The most common communication medium for designers was electronic data transfer. The use of other communication tools, such as virtual reality, Internet, and Intranet, was very low for both design and site teams.

Clarification of information regarding Constructability problems was carried out using 2-D drawings, written statements and face-to-face meetings. There was very low usage of physical and 3-D models by respondents. Other methods such as rendered images, video animation, VR, VRML, etc. were not used at all.

Interfaces between components and difficult assembly, had been widely experienced among the respondents as Constructability problems, especially with cladding, services, roofs, and stairs. Construction team experience was widely used to solve design problems when they occurred.

Contractors and consultants, who had used any form of visualisation, realised the benefits that could be gained from its use in construction. Therefore they were of the view that the use of visualisation would improve the communication of Constructability information in construction.

4. CONSTRUCTABILITY INFORMATION FRAMEWORK

The literature review and industry survey conducted established the requirements for the presentation and communication of design information. This section presents a framework for design information communication during the construction stage of a project that fulfils these requirements. This framework is intended to form the basis for the development of design support systems that facilitate Constructability information flow. The framework is called the Constructability Information Framework (Fig. 1).

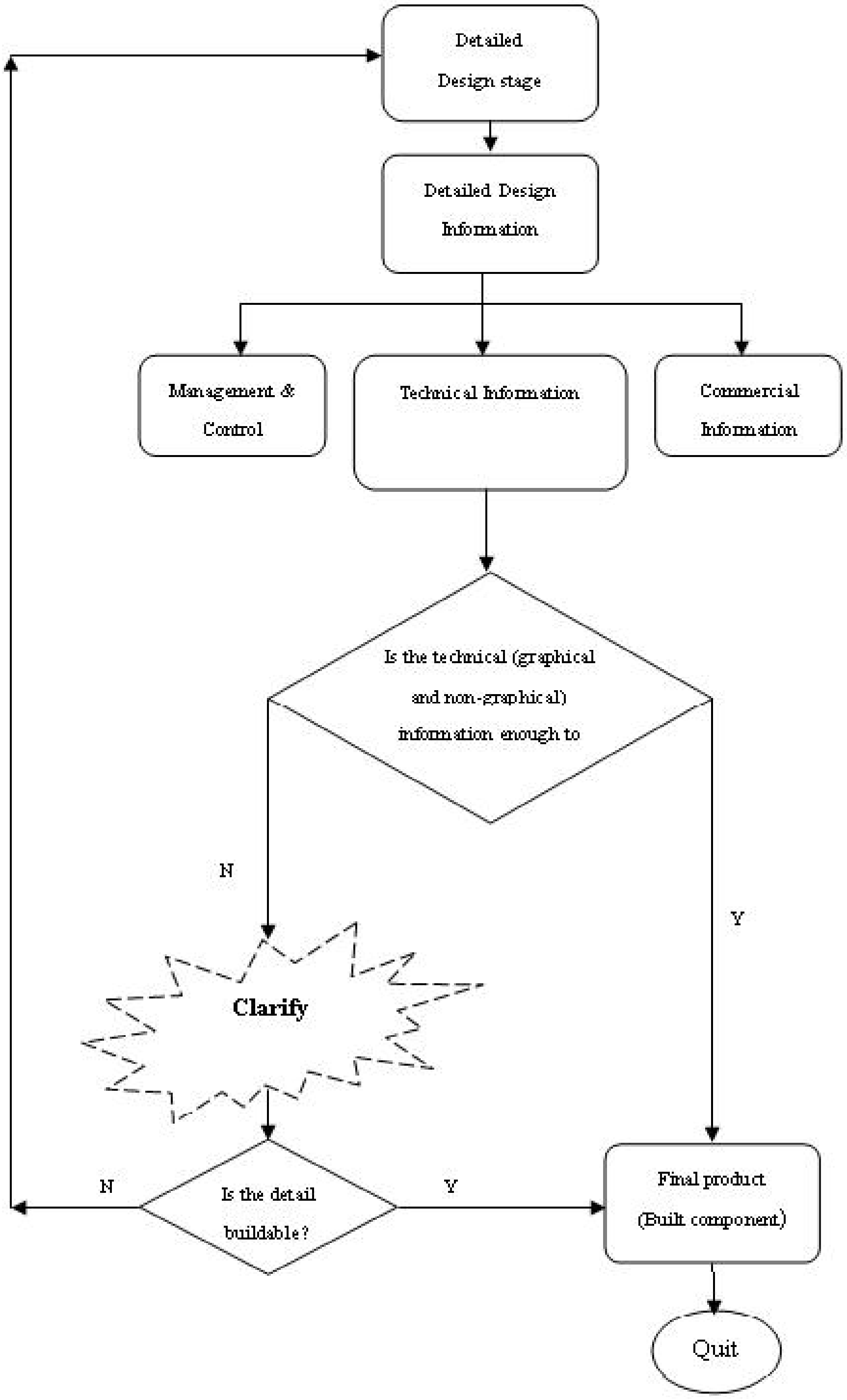

FIG. 1: Constructability Information Framework

The graphical information flow works as a diagnosis module. The diagnosis module analyses a given design, detects Constructability problems, and reports them to the site team. It explores the possible problems the site team may face in assembling components, and dealing with interfaces between different building components. The diagnosis begins with the extraction of a list of the common problem areas (cladding, roof, etc.). The design team checks if the contractor possesses the skills and experience to conduct specific details without facing any difficulty. It also checks if a specific design detail is clear enough, and whether 2D drawings are sufficient for communicating the design intents and decisions. As can be seen in Fig. 1, the design team may pass the design details assuming that it is clear enough and can be understood, but the site team cannot understand the design intent and decisions, and may face difficulties in implementing that part of the design. As the industry surveys (postal survey and case study interviews) showed that Constructability problems are not similar and differ from one building to another, the framework has been developed to be generic and not specific to certain building components (e.g. roof, cladding, etc.) or building types.

5. THE NEED FOR VISCON

The literature review and industry survey revealed that traditional tools are not adequate to communicate design intent and decisions. In addition, communicating information through paper-based graphical representation limits the design and construction teams' ability to work together to solve problems that arise during the construction stage of a building. Moreover, paper-based communication does not provide the interaction needed to focus a project team's attention on the most relevant information. Visualisation-based communication approaches can be more powerful than paper-based ones because they support the participants in co-ordinating the work and related information on projects by making interaction more effective. This was confirmed by the industry survey and case study interviews undertaken at the early stages of this research project. These showed that:

- Traditional visualisation and communication tools have serious limitations for the exchange of design information between design and site teams;
- Many Constructability problems are caused by the lack of clear and sufficient information to assemble certain building components, or by misunderstanding that information;
- Design details intent, and decisions were not always understood by the site team because these details were not clearly or well presented;
- The industry survey showed that the use of computer visualisation was limited to the conceptual design stage and mainly to present designs to clients to obtain their approval;
- There is a necessity for site visits by the design team to investigate problems that arise during construction, these visits are time and money-consuming;
- The collaboration between design and site teams is ad hoc and not properly organised (i.e. there was no conceptual framework for collaboration and communication between the two teams during the design and construction process)

Although there is a need for adopting computer visualisation as a communication tool for the exchange of design information related to Constructability problems at the construction stage of a facility, current research efforts do not adequately address the issue of the industry needs that computer visualisation can fulfil. The development of a system's architecture, for the use of computer visualisation to communicate design information, is, therefore, essential for improving communication/collaboration in the construction industry.

6. SYSTEM REQUIREMENTS

The literature review and industry survey identified the requirements of a system that can help in communicating detailed design information. The requirements analysis established a set of features that will be desirable to future users. The system should:

1. be based on standard PC hardware used in the construction industry;
2. support standard protocols for 3D modelling, rendering, animation creation, visual, audio and data communication;
3. use existing software, wherever possible, available at low cost or free of charge;
4. provide tools for data management or online record keeping; and
5. allow for asynchronous and synchronous collaboration.

7. VISCON ARCHITECTURE

A "visualisation system" is an interactive system that enables users to present data in a way that suits their purpose (Taylor, 2001). A visualisation system is not a system for making a picture out of some attributes of the data. Indeed, data presentation need not be wholly, or even partially visual, provided that it allows the user to visualise (i.e. to make a mental picture of) how the data fits the purpose.

The VISCON architecture is designed to use visualisation applications to clarify and communicate Constructability information (Fig. 2). The architecture can be assumed to be a closed loop of interaction between the designers, the VISCON system and the site team. The system consists of three main levels. The data flow, which is represented by arrows, uses the principle that information moves from one process to another. The levels represented in Fig. 2, transform data either by changing its form and adding to it or by generating new information. A process must have at least one data flow coming into it and at least one leaving it, except from two components: where the incoming data flow comes from or where it ends; the first is a data generator and the second is where data is stored or used to get the final product. The system architecture shows when the system is needed for clarifying design details using 3D visualisation. The system architecture helps the design team to choose which type of visualisation is appropriate for which part of the building with potential difficulties on site.

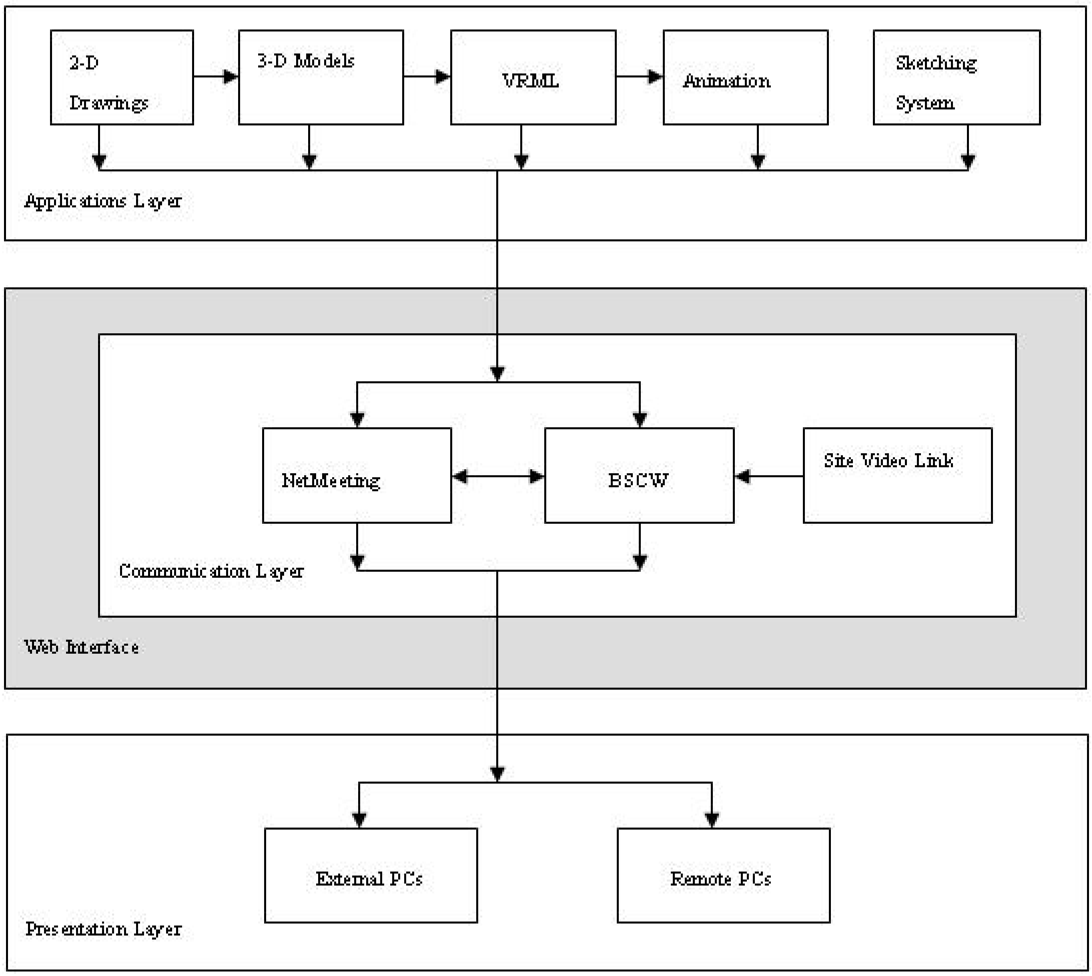

FIG. 2: VISCON System Architecture

The first level of the visualisation system is where the 3-D models are created from the 2-D drawings and textual information using a 3D CAD modelling tool. These models form the basis for the visualisation system. 3-D models are not as easy to produce as 2-D drawings or physical models. Each 3-D object can be created using one or more 3-D modelling techniques such as solid modelling techniques, or wire frame techniques. When creating 3-D models, each method has its own characteristic advantages and disadvantages. It is necessary to identify at the outset the best method for creating a 3-D model for a specific component of a building or for the whole building. Another method of creating 3-D models is the 3-D sketching tool. Sketching is a powerful means of communication between people, and while many useful programs have been created, current systems are far from achieving the same results as freehand sketching.

Having created the 3-D model, it can then be transferred to the rendering system. At this level, materials can be added to the 3-D model to give it a 'real' appearance. 3-D animation can also be set up and created during this stage.

At the third level, the outcome from the second level of the system can be a VRML model, 3-D animation, rendered image or any other visualisation. The decision on what type of visualisation should be produced depends on the information that should be presented. It also depends on the particular project and its constraints as well as on the way of working. If the visualisation aim is, for example, to show how components can be assembled, the best visualisation system to use is 3-D animation. To view the final product, it is best to use a VRML model, which can be manipulated and viewed from different angles and sides.

Rendered images are useful for visualising materials and their appearance. This enables users to decide on the best materials from an aesthetic point of view. VISCON also offers other visualisation systems currently available (such as VR) and is flexible enough to incorporate other systems that will be available in the future.

All visualisations and information on the design of a specific part of a project are created within the system and linked to the main drawing. 3-D animations, VRML, rendered images etc., can be hyperlinked to a 2-D plan of the proposed building or structure so that it can be downloaded from the Internet. This allows the viewing for the visualisation and information produced for a specific component. Site video link can also be set up by having a web camera on the construction site and linking it to the Internet or Intranet.

8. VISCON CASE STUDIES

This section presents practical experiments conducted to test the prototype system VISCON. Two case studies used data from real projects. These case studies were: a bay barrage building and a swimming pool. The case studies focused on Constructability problems with the assembly of cladding, roofs and stairs as the survey revealed that these problems were widely experienced by industry practitioners. In the development of the case studies, 3D models were created for some components that may inherently be difficult to assemble using AutoCAD. These models were exported to 3D Studio Viz for final editing. They may also be exported to VRML at this stage, but this requires additional editing work within one of the VRML builder packages. The editing process in 3D Studio Viz is as follows:

1. Import the AutoCAD 3D model making sure that the settings convert each entity from AutoCAD to a separate entity in 3D Studio Viz assigning realistic materials to each component to give the 3D model a realistic image.
2. Use the Track view window in 3D Studio Viz to add visibility track to every entity.
3. Set the visibility of each entity to correspond to a scaled sequence of its construction
4. Render the animation.

With 3D Studio Viz, the camera can be moved during the course of the animation to focus on particular elements being constructed. For example, while an exterior view is advantageous for illustrating the construction of the cladding, once the sheeting has been applied, the interior structure is hidden. With 3D Studio Viz, it is easy to group multiple elements and manipulate them as a group. It is also possible to illustrate the movement of constructed elements, to show for example how an unconventional staircase is assembled. In addition, 3D Studio Viz images and animations provide high quality imagery with ray trace shadowing and multiple light sources, which gives a good sense of three dimensions space. VRML models are simpler in terms of textures and lighting but offer real-time movement and an authentic sense of presence.

8.1 Case study 1 (Bay Barrage)

This case study was developed using a set of working details for a control building of a bay barrage. This set shows details of some parts of the structure of the building that may cause some problems for the builders. Each 3D model was created for a specific part of the structure. From these 3D models, VRML models and animations (Fig. 3 &Fig. 4) were created to show how the components of the specific part could be assembled. They also showed how different components interface with each other. As a 2D plan for the building was not available, an elevation was drawn using a perspective drawing of the building. This elevation drawing was used to create links to VRML models and 3D animations. The 3D models and the elevation were put on a Web site for collaborative viewing (Fig. 5).

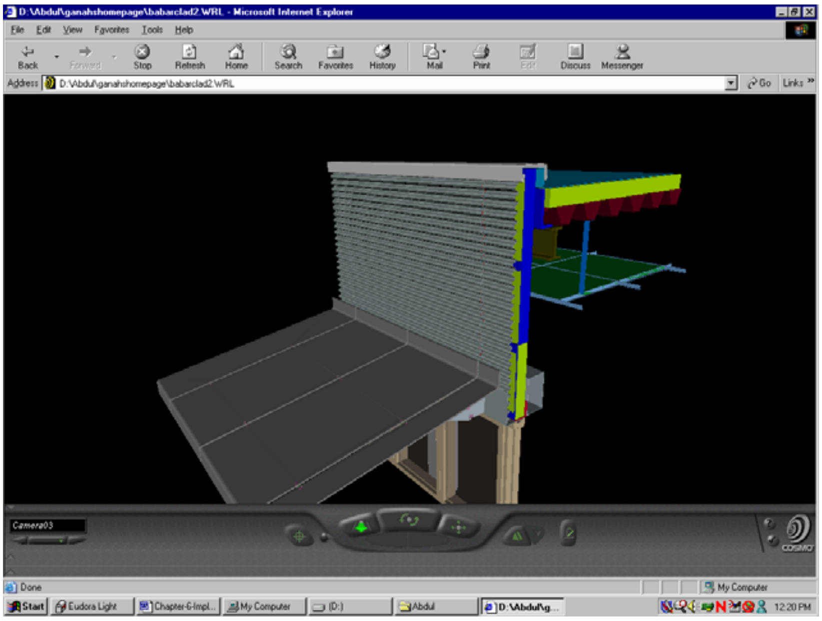

FIG. 3: VRML model for cladding showing the interface between different building components

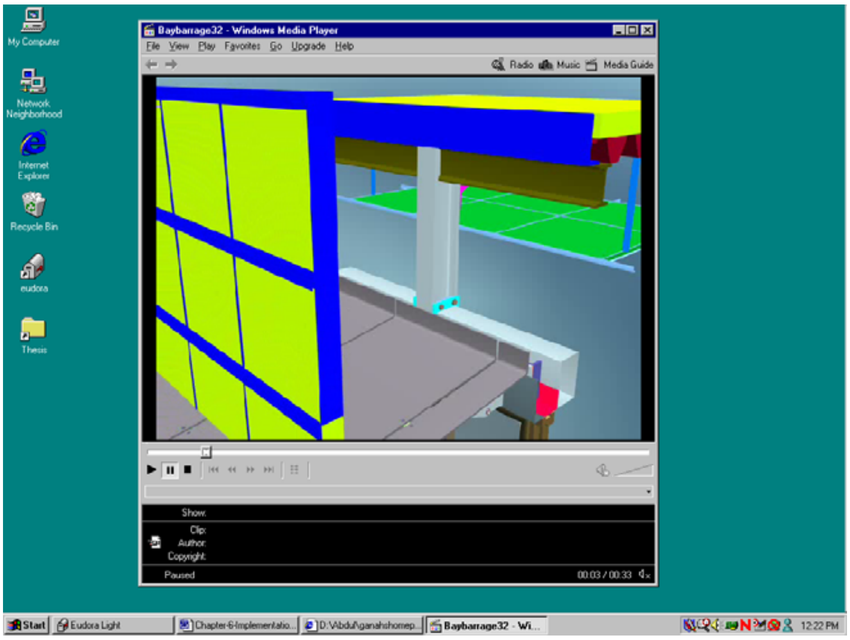

FIG. 4: 3D animation showing how building components can be assembled

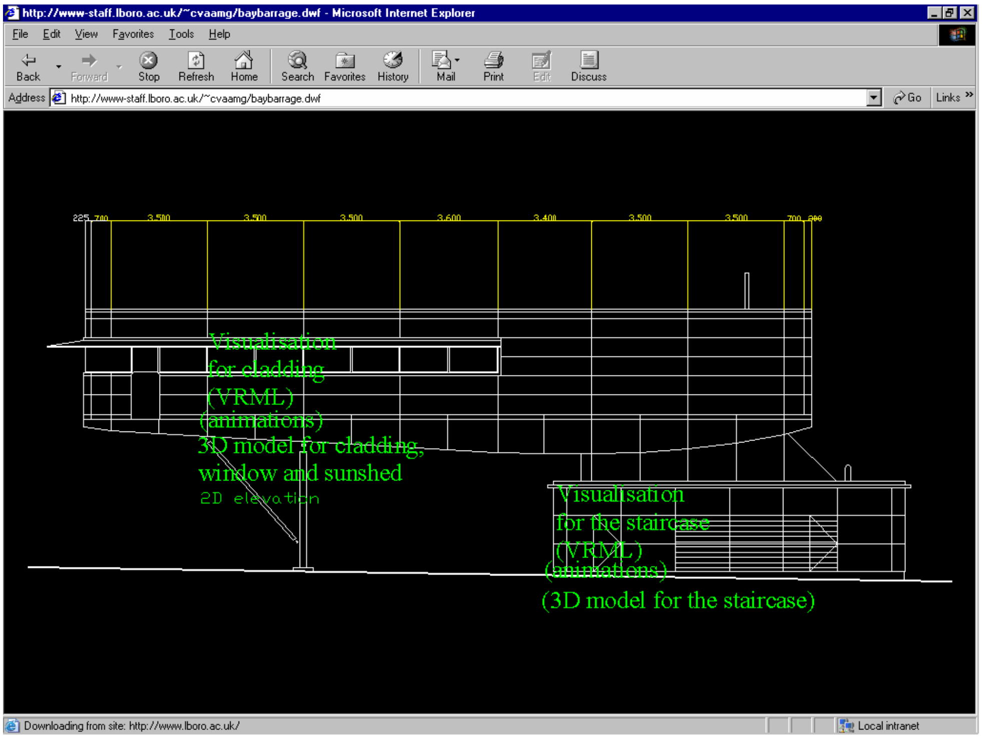

FIG. 5: 2D elevation drawing for the Bay Barrage Building with hyperlinks to the created visualisations

8.2 Case study 2 (Swimming Pool)

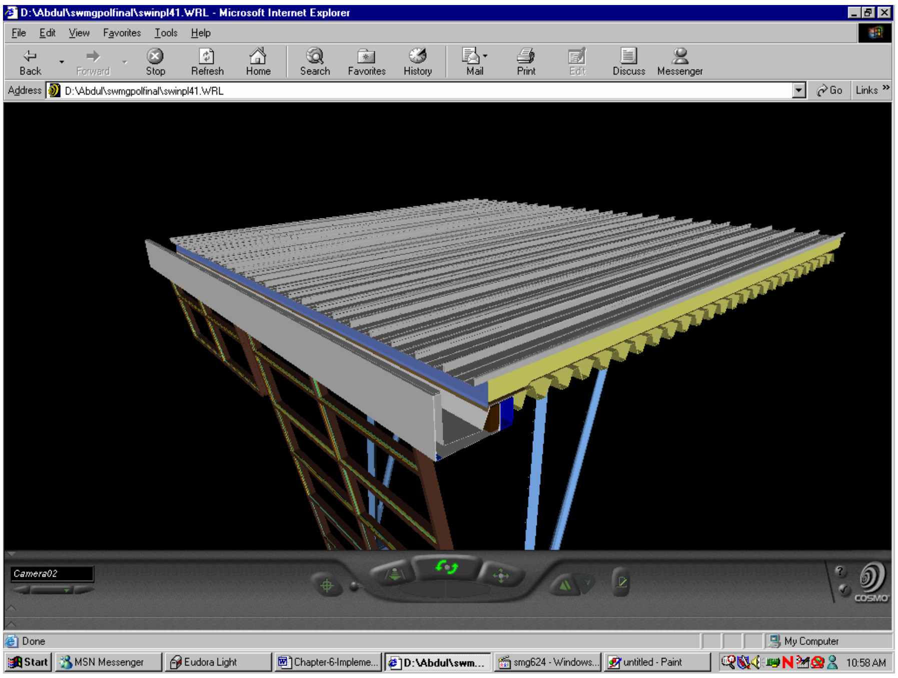

FIG. 6: VRML model showing gutter, insulation layers, ceiling and roof interfaces in the swimming pool building

This case study used a number of drawings for a swimming pool constructed at Loughborough University. The development of this case study differs from the previous in that it has been based on electronic CAD drawings. The case study produced models for three different areas. The first is a VRML model showing the main steel frame. The second is a model showing interface between the roof and the glazing components. The VRML model shows how these components interface (see Fig. 6). The animations show how some of these components can be assembled (see Fig. 7). The third model shows the interfaces between the roofing components (the insulation layer, the ceiling and the sheeting) and the gutter components. The VRML model shows the interface between these components. The animations show how the gutter and waterproof components can be assembled. The 2D plan of the swimming pool was used to create the links to the VRML models and 3D animations. This plan was saved as DWF (Drawing Web Format) so that it can be put on the Internet or Intranet (Fig. 8).

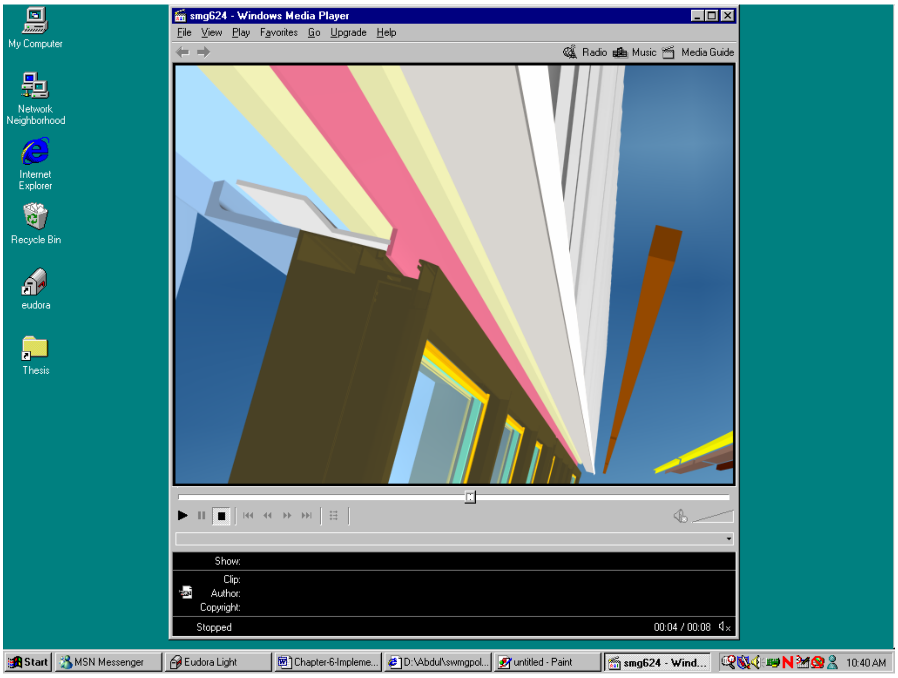

FIG. 7: 3D animations showing how the insulation layers and other building components can be assembled

FIG. 8: 2D plan for the swimming pool with hyperlinks to VRML models and 3D animations

9. FINDINGS

During the development of the case studies presented above, some interesting findings were reached:

- Building 3-D models can be a lengthy process, however there are many different ways of producing them; each method has its own advantages and disadvantages. It is necessary to identify at the outset the best method for the task in hand.
- CAD systems are the source of most graphical data in a project. Many of the commercial CAD systems used by construction firms are primarily geometry modellers and use several file formats (3DS, DXF, OBJ, etc.). The complete data transfer process from CAD to VRML is shown in Fig. 9. As VRML modelling software do not provide sophisticated modelling techniques used in traditional CAD systems, 3D models therefore need to be created using one of the 3D CAD modelling software. These models can then be transferred to VRML.
- Translating from the file formats mentioned above to VRML is not accurate and can lead to poor models. The translation is usually a one-way or downstream process (Fig. 9). The 3D CAD model can be translated into VRML either directly or through an intermediate stage using a rendering package. However, the quality of the VRML model created by direct translation from CAD is of less quality than that created using a rendering package. To facilitate the translation process, the data structure of the 3D CAD model must be re-ordered so that it is acceptable to the destination application. For example, a 3D CAD model created in AutoCAD must be exported in a format that can be imported by 3D Studio Viz.
- 3-D modelling helps in identifying any missing information for building a particular component as creating 3D models requires all information to be available.
- The sequence of assembling building components can be easily established.
- By modelling design details, decisions can be made on the design and the results can be seen before the construction starts.
- Building 3-D models for part of a building that contains a Constructability problem is much more efficient and less time consuming than creating a 3D model for the whole building especially if the hardware is limited.

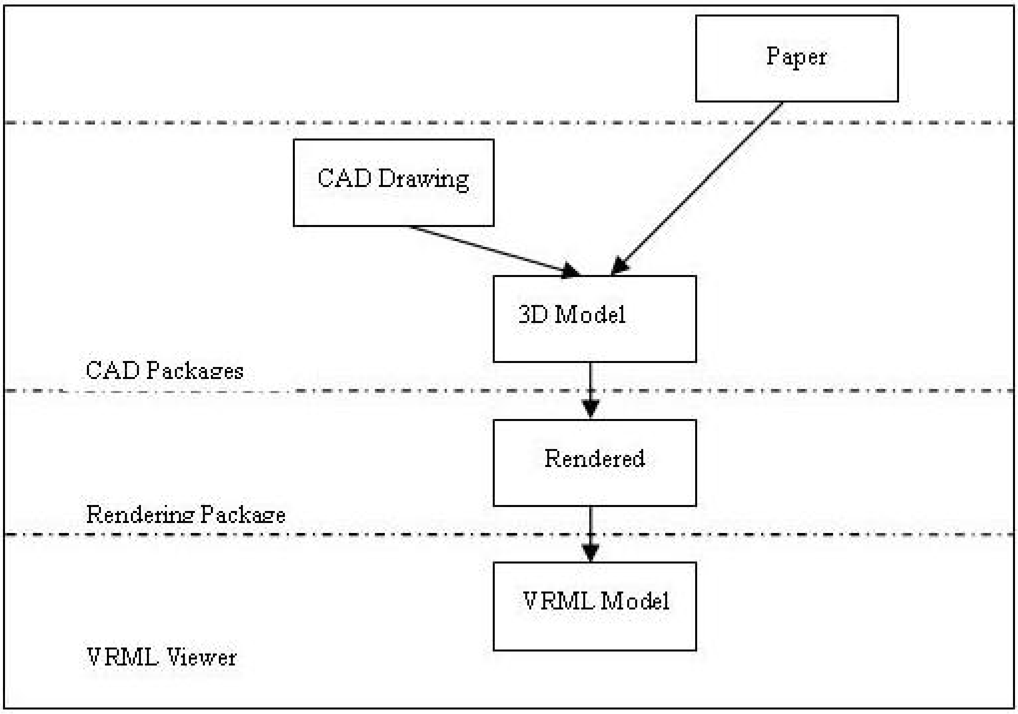

FIG. 9: Translation of file formats from CAD to VRML

10. VISCON EVALUATION

The primary aim in evaluating the VISCON system is to identify areas that require improvement. The evaluation was carried out during the final stages of the system implementation and involved two groups; the first group consisted of 11 researchers and the second group consisted of 18 practitioners from five contactors and consultants. In the first session, 11 researchers participated, a brief description of the system's architecture was given to the evaluators together with brief details on how the VSICON case studies were developed. This was followed by demonstrations of the two case studies. The demonstrations included explanations on how VISCON can be used to study the interfaces between different building components and show their assembly sequence. Finally a discussion took place where the evaluators asked questions relating to the system and the research project.

TABLE 1: Researchers Specialisation and Experience

Previous position in construction industry	**Experience (Years)**
Construction Manager	25
Building Engineer	3
Design consultant	14
Structural Engineer	10
Civil Engineer	10
Civil Engineer	3
Architect	2
Building Consultant	20
Structural Engineer	4
Civil Engineer	9
Civil & Structural Engineer	2

The second evaluation session built on the first one and improved the method used and information supplied to evaluators. Therefore, a brief summary of the aim of the research and the proposed system was given to the evaluators. A demonstration for the VISCON case studies was shown as above. After the demonstration, the evaluators were invited to ask questions on the system. At the end of the evaluation session, the evaluation questionnaire was handed out for feedback.

As it has been mentioned earlier, evaluators from the first session were a group of researchers in Civil and Building Engineering Department at Loughborough University. Most of them worked in the construction industry and six of them had more than 10 years experience (see Table 1). The evaluators had either architectural or civil engineering background. Although they currently work in an academic environment, they have been actively involved in industrial practice and have had close connection with practitioners making them fairly representative of the potential users of the VSICON prototype. Therefore, the experience of the participants was considered to be adequate to enable an objective assessment of the system.

The group, who participated in the industry practitioners' evaluation session, consisted of a broad range of professionals who worked in the construction industry for many years in deferent positions including IT experts, structural engineers, architects, civil engineers and researchers in construction management. They represented five firms with an average of 6360 employees, and an average annual turn over of £54.4 m (see Table 2). These evaluators were considered suitable as each one had a specific area of expertise that is related to the development of the proposed system under evaluation. Except for the two principal engineers, all the others are directly involved in the daily design activities. Table 3 shows the evaluators positions, specialisation and experience.

TABLE 2: Details about industry evaluators' Organisations

Firm	Number of Employees	Annual Turnover
A	26,000	£70m
B	1,800	£85m
C	1,200	£40m

D	300	£17m
E	2,500	£60m
Total	*31800*	£272m
Average	6360	£54.4m

TABLE 3: Industry practitioners Specialisation and Experience

Position	**Area of experience**	**Experience (Years)**	**Position**	**Area of experience**	**Experience (Years)**
IT Associate	Structural Engineering, IT & 3D Modelling	8	Architect	Visualisations (3D)	1
Facade Architect	Architect	13	Design Engineer	Civil & Structural Engineer	5
Façade Engineer	Structural Engineering & Facades	4	Associate Engineer	Civil Engineer	20
Structural Engineer	Building	25	Engineer	Building	5
Principal Engineer	Building	19	*Associate Engineer*	Building and Structural Engineer	20
Principal Engineer	Building	15	CAD Technicain	Buildings	30
CAD Co-ordinator	*Building Services, Architecture, Building Surveying*	8	Design Consultant	Electrical Engineer	6
Engineer	Civil Engineering	4	Structural	Civil & Structural	5
Engineer	Civil Engineering	1	Senior	Building	15

11. DISCUSSION & EVALUATION OF RESULTS

Despite the selection of the evaluators in both sessions not being random, they were sufficiently representative of potential end-users of the system, in that they possess adequate experience in building design and construction, or have been involved in the manufacturing of building components. The experience of the evaluators and their specialisations therefore can be considered as adequate for the assessment of the proposed system. This mix of expertise and background can also be considered as adequate for an objective evaluation and assessment of the proposed system.

The performance of VISCON was generally judged to be satisfactory (see Table 4). The rating of the questions in the questionnaire showed that VISCON can adequately perform the function for which it was designed and fulfilled the requirements. All the participants in the evaluation sessions were generally satisfied with the effectiveness of the system in communicating and clarifying design details that may cause some difficulty on site.

Most of those who took part in the evaluation were impressed with the quality of graphics used in the system. There was also an agreement that the graphics and the hyperlinks between the different models created to show how different building components interface and how they can be assembled help the design team to convey their design intent to site teams where 2D drawings and text information are not enough to do so. The industry practitioners, especially those who use 3D modelling, liked the system architecture and believe that it would be very helpful for people who currently use computer visualisation as well as those who are planning to introduce it in their organisations.

The relatively low rating (69%) for the questions on the efficiency of the system in improving the speed of information flow during the construction stage was probably due to lack of understanding of how the communication system within VISCON works. The other question that received similar scores (69%) was the one related to the usability of VISCON in the construction industry. On this point, all of the participants commented that the decision makers in the construction industry have the view that investment in computer visualisation is the field with least return. The other reason is that most of the decision makers came from paper-based school.

Generally, it can be said that the evaluation was a success. Although the system has some limitations, the evaluation results have shown that the system effectively supports Constructability information communication. Overall, experts in the construction industry and the researchers who participated in the system evaluation have rated the VISCON performance as satisfactory. The results of the evaluations are summarised in Table 4.

TABLE 4: Summary of Evaluators' Response to the evaluation questionnaire

a) Constructability information communication

Questions		Evaluators Rating (out of 5)			**Overall %**
		Resear. Averg.	Indust Averg.	**Overall Averg.**	
1	How well does the system facilitate the clarification of design information / details?	4.0	3.8	**3.9**	**78%**
2	How well does the system support the communication between designers and contractors?	4.3	3.6	**3.9**	**78%**
3	How well does the system help in understanding how components can be assembled?	4.4	3.9	**4.1**	**82%**
4	How well does the system help in clarifying the interfaces between components?	4.1	3.6	**3.8**	**76%**
5	How well the system complement the paper based communication tools?	4.1	3.8	**3.9**	**79%**

b) Applicability to the construction industry

6	How appropriate are the visualisation tools used in the system?	4.3	3.5	**3.8**	**76%**
7	How well does the system architecture support the flow of graphical information?	4.5	3.3	**3.8**	**75%**
8	How well does the system address the poor design details?	4.1	3.3	**3.6**	**72%**
9	How well does the system clarify conflicting design information?	4.1	3.7	**3.8**	**77%**
10	How well does the system increase the speed of the information flow during the construction?	3.9	3.2	**3.5**	**69%**
12	How convinced are you that construction industry professionals will accept the system?	3.8	3.2	**3.5**	**69%**

c) Management of the system

13	How well is the system architecture?	4.1	3.2	**3.5**	**71%**
14	How easy is the system to use?	4.1	3.2	**3.5**	**71%**
15	How well integrated are the different components of the system?	3.6	3.2	**3.4**	**67%**
16	To what extent is the system flexible for choosing the most suitable of visualisation tool for clarifying and communicating information?	3.5	3.6	**3.6**	**71%**

d) Efficiency

17	How efficient is the visualisation system during the construction stage of a project?	4.1	3.5	**3.7**	**74%**
18	How effective is the communication system during the construction stage of project?	4.1	3.2	**3.5**	**71%**

E) General

19	How confident are you with computers (generally)?	4.5	4.2	**4.3**	**86%**
20	How generic do you consider the system to be?	3.8	3.8	**3.8**	**76%**
21	What is your overall rating of the system?	4.1	3.7	**3.8**	**77%**

12. ANTICIPATED BENEFITS OF VISCON

Although there is room for improvement, the prototype system VISCON provided an effective tool for communicating design information related to Constructability between design and construction teams. Its effectiveness was proven through the evaluation questionnaire results. Through the evaluation of the system, several practical benefits were demonstrated. These include:

- The commercial packages used in VISCON are tailored for the construction industry practitioners' need, thus savings in the form of time and cost can be expected.
- The development of the system within an established framework ensures that such a development is not done on an ad-hoc basis. This will allow the construction industry practitioners to use the system in situations suitable to their business; as a result the business may become more competitive.
- The use of VRML to present interfaces between different building components and 3D animations to show how these components can be assembled, can reduce Constructability problems caused by the misunderstanding of design information. There are big benefits that can be gained from using VISCON, these benefits include but are not limited to reducing waste, rework, and cost; and delivering a high quality product.
- The development and implementation of the system were carried out on a PC with standard hardware within a window environment. This ensured that the developed product is within the reach of most construction firms.
- The participants in the industry survey that formed the basis for the system development, have become aware of recent technological advances which can help their business.
- The communication and collaboration tools used in the system ensures that the communication and collaboration in the construction sector is improved resulting in better productivity. The developed system covered important areas such as transfer of the design information between the design and construction teams to reduce the amount of rework caused by improper information communication.

Nevertheless there are still limitations in using the VISCON system. The following section discusses these limitations.

13. ANTICIPATED BENEFITS OF VISCON

Comments made by the evaluation participants have highlighted some of the limitations of the system, which include:

- Although the main aim of the system is the communication of graphical information, the system does not support textual information;
- 3D animations, 3D modelling and rendering requires powerful computers to work at reasonable speed and efficiency.
- 3D models need to be created using one of 3D CAD modelling software then exported to VRML. This process is not straightforward which can lead to poorly formatted and inefficient VRML files.
- Lack of texture in VRML made the models less realistic.

14. BARRIERS TO THE USE OF VISCON IN THE CONSTRUCTION INDUSTRY

The major barriers that may restrict the benefits that could be gained from the use of VISCON in the construction industry are as follows:

- Lack of knowledge of what computer visualisation can provide among construction industry professionals especially decision-makers, and the attitudes such as "we have never done that before" and "this is what we did on the last job and it worked then, so why do something different now?";
- The real or perceived high cost of advanced computer graphics, especially in the high cost of software for the organisation who do not use advanced CAD and visualisation software such as 3D modelling and rendering;
- The time required to adequately train staff in the use of computer systems.

15. CONCLUSION

The VISCON system is computer network-based providing users with access to the technology and the necessary knowledge to use it. It presents several advantages over conventional methods of communication and collaboration. In the latter, all the members of the team must be located in the same physical space. It is obvious that phone communication and teleconferencing along with facsimile could be used instead of conventional gatherings. Unfortunately, these methods (facsimiles in particular) do not aid the unified databases of a project but rather cause the reproduction of project information on paper. The proposed system overcomes these limitations; the users of the system could be located virtually anywhere there is access to global area network or local area network (LAN).

VRML modelling and animations are good tools for advancing the use of computer visualisation in the construction industry. Integration of the VISCON system in the design and construction process will reduce the gap between the two. The system developed would help create, with relatively little effort, 3D animations showing how construction details can be assembled to avoid building failures due to contractors not understanding the details as presented in conventional, two-dimensional representations. VRML offers good potential in assisting practitioners to understand more about the construction process and Constructability analysis.

16. REFERENCES

Alshawi, M. and Underwood, J. (1996), Improving the constructability of design solutions through an integrated system Engineering, *Construction and Architecture Management,* Vol. 3, No. 1, 47–67.

Alshawi, M. and Underwood, J. (1999), The Application of information Technology in the management of Construction, RICS Research, London.

Bennet, J. (1985), Construction Project Management. Butterworths, London.

CLL (1998), Corporate Lessons Learned. Construction Engineering Research Laboratory, U.S. Army Corps of Engineers, {http://www.cecer.army.mil}.

Construct I.T. (1995), Bridging the Gap: an information technology strategy for the United Kingdom construction industry, Department of the Environment in association with BT.

Egan, J. (1998) Rethinking Construction: report of the construction task force on the scope for improving the quality and the efficiency of UK construction, Department of the Environment, Transport and Regions, London.

.Fischer, M. A. (1993), Automating constructability reasoning with a geometrical and topological project model. Computing Systems in Engineering. Vol. 4, No. 2, 179–192.

Kuprenas, J.A., Um, J.T. and Booth, C.E. (1995), Use of CAD Three-dimensional Modelling as a Constructability Review Tool. Proceedings of 2nd Congress of Computing in Civil Engineering. Atlanta, GA, USA, 195-202.

Navon, R. Shapira, A. and Shechori, Y. (2000), Automated Rebar Constructability Diagnosis, Journal of Construction Engineering and Management, Vol. 126 No. 5, 389-397.

New Civil Engineer (1999), Contractors and Consultants file.

Newton, C. (1998), Architecture as Alchemy: Changing documentation languages and their translation into built forms. Proceeding of 1998 IEEE Conference on Information Visualisation in London, IEEE Computer Society, Los Alamitos, USA.

Snook, K. (1995), Construction Papers: CPI-Co-ordinated Project Information, The Chartered Institute of Building, Ascot.

Taylor, M.M. (2001), Guidelines for Evaluating Visualisation System Designs and Specifications, (www.vistg.net/documents/Working%20Papers/guidelines.html).

Wakefield, R.R. and Damrianant, J. (1999), Petri Nets a tool for construction process re-engineering, Journal Of Computer Integrated Design and Construction, Vol. 1, No. 2, 20-34.