THE USE OF VISUALISATION TO COMMUNICATE DESIGN INFORMATION TO CONSTRUCTION SITES

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Architectural drawings, physical models and sketches are the main visualisation tools used in building design. They are accepted methods of communication between designers and builders. However, these tools are not adequate to provide sufficient information about design ideas and details to builders. Computer visualisation can effectively be used as a communication tool between design and construction teams that are geographically dispersed.This paper describes a research project that is concerned with how computer visualisation can be used during the construction stage of medium and high-rise buildings to facilitate communication between the construction site team and the design team, ensure adherence to design details, and provide specific guidance in complex assembly and/or construction operations. An industry survey questionnaire was carried out to investigate the current use of visualisation in communication between design and construction teams. The preliminary analysis of the results shows that the most common methods used by designer and site teams for clarifying information about buildability problems were traditional tools and methods, which have serious limitations in supporting virtual construction project teams.

Keywords: information, visualisation, communication, construction.

INTRODUCTION

Computer visualisation has become a field that designers are currently seeking to exploit as a new technology to cope with a rapidly changing construction industry where new materials and construction techniques are constantly developing, labour costs are increasing, and environmental issues are becoming more and more important (Newton, 1998).

Future architectural practices will be supported by information technology where the design is presented as a data base of geometric and text information, so that paper based images and documentation will only be a form of information extracted from the data base (Seebohm and Wallace, 1998). Project information visualisation is not only important at the design stage but it is also becoming increasingly important at the construction stage. It can be a valuable tool for supporting other systems with respect to construction sequence, equipment access, work accomplished and problem areas (Alshawi and Underwood, 1999). In addition to that, visualisation and communication could improve collaboration between site and design teams in solving buildability problems that may arise during construction (Construct IT, 1995).

During the construction process, builders face several problems. Some of these are complicated, difficult to understand and build. Too much time and effort are spent trying to understand the design intent and making it work. This means that they have

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to wait for the site management team to explain how it could be done (Bennett, 1985). The site management team may need to contact the designer to clarify these details and ask how it could be implemented. This may require additional drawings and sketches to be prepared. It is estimated that nearly 30% of all quality problems and 15% of serious quality problems occurring on a construction site were due to unclear project information (Snook, 1995).

This paper presents a research project that is investigating the use of computer visualisation and communication during the construction process. It is in four parts: the introduction includes the aim and objectives of the research, hypothesis, and the methodology. The following sections discuss information visualisation and communication; the industry survey; and the last section includes the conclusions and future work.

THE AIM AND OBJECTIVES OF THE RESEARCH

The main aim of the research project is to study the potential use of computer visualisation and computer mediated communication in building construction to reduce waste and rework in construction, and to ensure that information is transferred properly, correctly, and in time. In order to achieve the aim, this research has focused on the following objectives:

Review existing visualisation tools and communication infrastructure in building construction practice and construction companies;

Review types of information, their supply, and difficulties especially at site level;

Develop system specification;

Develop a prototype system and validate it (in field trials).

HYPOTHESIS

The hypothesis of the research is that traditional methods and tools of presenting design details, and existing communication media between designers and construction teams are inadequate to support the complexities of modern construction. Therefore, the use of computer visualisation tools will improve communication between design offices and site teams, and insure proper and correct implementation of design, and facilitate the collaboration between site and design teams to solve buildability problems.

METHODOLOGY

Literature Review

A literature review of previous similar works that have been published in journals or presented at conferences was undertaken; this will be continued and updated throughout the project duration. This has revealed that, up to now, very little work relating to collaboration during the construction process has been conducted. A summary of the findings of the literature review is included in the section on ‘Information Visualisation and Communication’.

Industry Survey
In addition to the literature review, it was considered useful to undertake an industry survey to establish the current situation within the construction industry. Specifically, it was expected that the survey would:

Highlight the problem areas and how they were dealt with in practice;

Ascertain potential problem areas requiring visualisation support;

Explore the potential for the use of visualisation to enhance site level work;

Establish the current level of usage of visualisation on construction sites.

Details of the industry survey are included later in the paper.

INFORMATION VISUALISATION AND COMMUNICATION

Information types
Project information can be classified into technical, commercial, or control information as shown in Figure 1 (Construct IT, 1995):

Technical Information: is information that describes the geometry of a building and its technical evaluation. This type of information can be divided into two main categories graphical or non-graphical information.

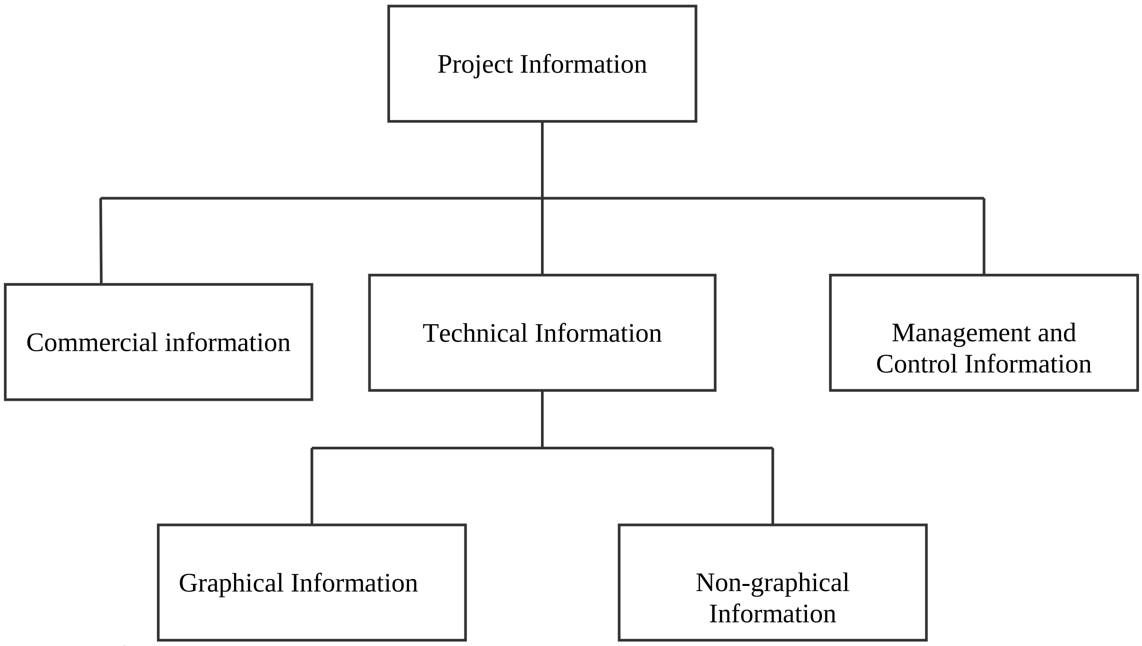

Figure 1: Information types in construction

Commercial information: is information that establishes the responsibilities of each participant in a project for the delivery of the final product. It includes delivery schedules, costs, payment schedules and terms and conditions of the contract.

Management and control information: includes all the information required to control a project, to generate reports, etc.

Information Visualisation
Visualisation is the display of information to maximise comprehension. Designers rely on architectural documentation to communicate their design to a construction team. In building design, computer visualisation allows investigations to iron out difficulties

that may occur before construction commences on site (Li and Love, 1998). The spatial relationships between elements in design can be observed and judged by the eye. Hand and eye co-ordination when placing objects is crucial. Computer visualisation, as with physical models, combines hand and motion with visual feedback about relationships between objects located in space.

The rapid growth of visualisation applications in different fields including building design and construction is due to several tangible benefits such as: (Brown et. al., 1995 and Gallougher, 1994):

We can simulate something in real life;

Computer simulation allows the observation of phenomena that may be difficult or dangerous and sometimes impossible to reproduce physically;

It allows us to evaluate automated design changes and analysis results;

Visualisation allows a faster and more thorough design process.

It makes the conversion of information that cannot be perceived by the human eye into forms suitable for the most highly developed human sense possible;

Three-dimensional visualisation techniques allow the examination of complex phenomena that may not be possible to see through the external surface of an analysis model;

It provides us with much less physical testing at often substantial cost savings.

Communication

Communication between the site team and other participants in construction projects is still performed using traditional methods, i.e. paper based drawings, schedules, written statements etc. The construction industry is in the habit of communicating through such methods and reluctant to adopting new technology. The use of telecommunication systems such as facsimile, e-mail and mobile phones has improved the communication in respect of speed but it has not influenced the efficiency of the process or the quality of information exchange (Alshawi and Underwood, 1999).

Construction projects often involve a number of participants from different disciplines. The most important thing is to understand how the participants interact. Wilson and Shi (1996) have stated that the behaviour of the design team participants depends on the following factors:

Organisational structure, which defines the participants' roles and co-ordination approaches.

Structure of goals that direct the task of each participant.

Communication which includes both the communication medium and the core knowledge which form a basis for mutual understanding of team participants.

Resources which allow the participants to perform their functions.

Bennett (1985) has stated that there are two categories of interaction, which match the basic characteristics of teams:

The first is concerned with the communication of information. Information should be first translated into text or graphics that the other team is likely to understand. These texts or graphics need to be communicated to the other team through a communication medium.

The second category of interaction is the one concerned with work organisation. Clear organisation of work allows the work of teams to fit together. In other words, teams should co-ordinate their actions.

Computer-supported communication may include (Cicognani and Maher, 1997a; Anumba and Duke 1997):

Electronic mail (e-mail) is regarded as the fastest, cheapest communication medium between people who have access to a computer network. Messages can be sent from one person to another who has a unique address or e-mail address. However, e-mail is regarded as the universal network communication media for computer mediated communication for collaboration. This is mainly due to the low cost, high level of information management, high level of connectivity, platform computability, and transcendence of time and space (Sudweeks and Allbritton, 1996).

Video Conferencing This type of computer communication allows a group of people to have remote participative discussion through video links. It provides a good means of communication between two or more participants who may be far away from each other.

World Wide Web (WWW) also known as the Internet. The World Wide Web is a network of computers geographically distributed all over the world. The information on it can be exchanged and communicated. Any person in the world can get access to information that has been made available on the web, except that information have restricted access where password is required. World Wide Web pages that record design information can be effective tools for design collaboration.

Networked Applications such as CAD, 3-D modelling, shared database or files, virtual meeting rooms, etc. The transfer of text is regarded relatively easy compared with the interchange of graphical information. This may cause loss of information. To eliminate the loss of information during the exchange, DXF (a file format for graphical data) has been developed and is now widely used in construction design. 3-D modelling may be shared between the design team to collaborate in reaching the best design results. The participants in the design and construction of such buildings can concurrently work and view a 3-D model of the proposed object (building or structure). This 3-D model can be used at all stages of design and life cycle of the object.

Electronic bulletin boards in which massages can be posted to a location accessible to others makes the information available for use by other design team members at any time anywhere. The information can be in any electronic format such as text, graphics, CAD models, etc. To get optimal benefits from the stored information, a well-established management should be set to enable the creation, reuse and distribution of this information.

Virtual reality Virtual Reality communication differs from other computer mediated communications in that it establishes a completely artificial communicative context (Deorry, 1995). VR systems remove users from their individual physical contexts and bring them together in a shared virtual communicative context. There are two main different types of Virtual Environment supported collaboration: geographically remote collaboration and collaborative virtual environment (Fuhrmann *et al.* 1994).

The use of an efficient communication system will improve communication, reduce travel and improve collaboration in solving problems between design and construction teams (Alshawi, and Underwood, 1999).

INDUSTRY SURVEY

The questionnaire structure

To achieve the aims of the survey two questionnaires were designed to gather information. Efforts were made to ensure that the questionnaires were not too elaborate for the respondents. The questionnaires were included 16 questions and were divided into 5 categories: general information about the organisation; visualisation and communication tools available; buildability areas with potential problems during construction; collaboration between site team and design team in solving design problems, and assessment of visualisation and communication tools and methods. The first questionnaire was sent to contractors and the second was sent to consultants.

The questions were a closed type, but with built-in flexibility so that the respondents could include additional comments where appropriate. There are two benefits of closed questions: first, it is easier for the respondent to answer, and second it provises a way to get rid of unrelated answers.

The sample

The target groups were contractors and consultants who build or design medium to high rise buildings. A total of 50-survey questionnaires were sent to contractors in March 2000. They were selected at random from the top 100 UK contractors based on turnover (New Civil Engineer 1999) and the fact that one of their fields is building construction. The number of questionnaire replies mailed back by respondents (see Table 1) was 28. Of these 10 replies were unusable, representing a response rate of 36%.

Table 1: Statistics of the contractors' survey questionnaires

Number of questionnaires sent	50
Number of replies received	28
Number of positive replies	18
Per cent of total replies	56%
Percent of positive replies	36%

The second questionnaire was sent to a total of 50 consultants in March 2000. These were sampled from the top 100 UK consultants in terms of turnover (New Civil Engineer 1999). The total number of replies (see Table 2) was 16 replies. Of these 5 replies were unusable. This left a total of 11 usable replies, representing a response rate of 22%. The overall response rate (see Table 3) was 29%.

Table 2: Statistics of the consultants' survey questionnaires

Number of questionnaires sent	50
Number of replies received	16
Number of positive replies	11
Per cent of total replies	32
Percent of positive replies	22

Table 3: Statistics of the survey questionnaires

Number of questionnaires sent	100
Number of replies received	44
Number of positive replies	29
Per cent of total replies	44%
Percent of positive replies	29%

The results

The two questionnaires were designed to investigate the use of computer communication and visualisation during the construction stage of medium to high-rise buildings in respect of 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 buildability problems that might arise during construction. A preliminary analysis of the results was carried out. This analysis indicates that:

Computer communication: The most common use of computer communication is e-mail especially by site teams to communicate with their organisation head office, subcontractors, and supply chain. The most common form of communication media for designers was electronic data transfer. The usage of other communication, such as virtual reality, Internet, and Intranet were rated very low.

Visualisation tools: 24% of contractors used 3-D models as visualisation tools 'Sometimes' to 'Frequently'. 64% of consultants used 3-D models as visualisation' at conceptual design stage 'Sometimes' to 'Frequently. The other visualisation tools such as animation, virtual reality, rendered images were rarely or never used by both respondents (contractors and consultants).

Buildability problems: Interfaces between components of services installations was the most common problem (see Figure 2) appearing in the 'Sometimes' to 'Frequently' category. It represents 67% for electrical installations, 64% for plumbing works, and 82% for mechanical installations. The other buildability problem area was cladding. 75% of the total respondents have 'Sometime' or 'Frequently' experienced problems of interfaces between cladding components. Stairs were regarded by 71% of respondents as another buildability problem. The roof was the most problematic area with regard to difficult assembly. This was the view of 71% of all respondents. In general, the most common problem was interfaces between components in all buildability areas. Between 32% and 82% of the total respondents have experienced 'Sometimes' to 'Frequently' this problem.clarification of information regarding buildability problems was carried out using 2-D drawings, written statements and face to face meetings (see Figure 3). 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.

DISCUSSION

The results of the survey questionnaires sent to UK contractors (site teams) and consultants (designers) concerning the current use of computer visualisation and communication tools in construction, and buildability problems that most frequently occur during the construction process, and the methods used to clarify information them have been presented. These results show 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 were accustomed to these methods and tools and found them easy to use. These methods and tools were not adequate and fast enough in communicating requests for information. The respondents thought that delays and lack of adequate information during the construction process might contribute 21-30% of the total delay of a project.

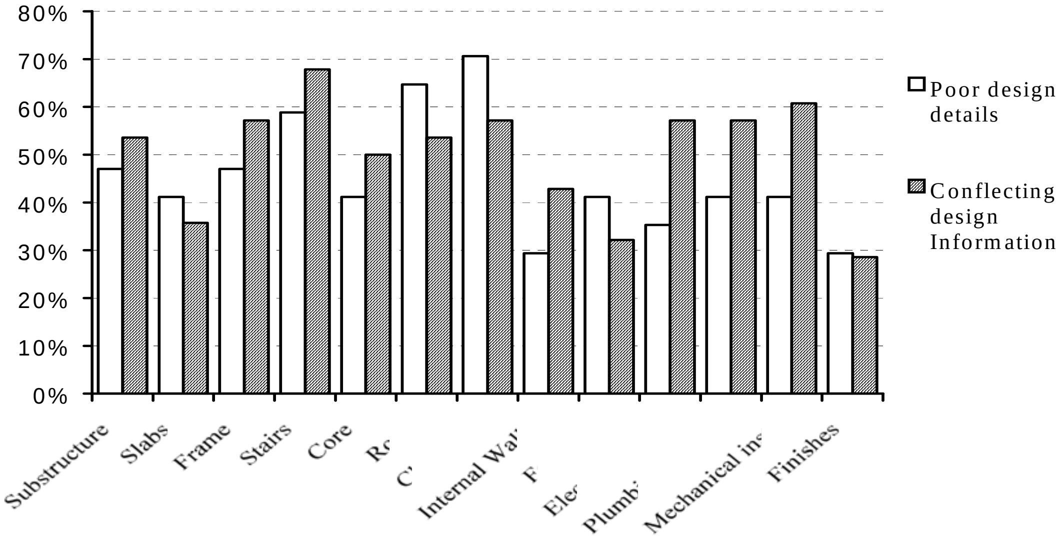

Figure 2: Reasons for buildability problems

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

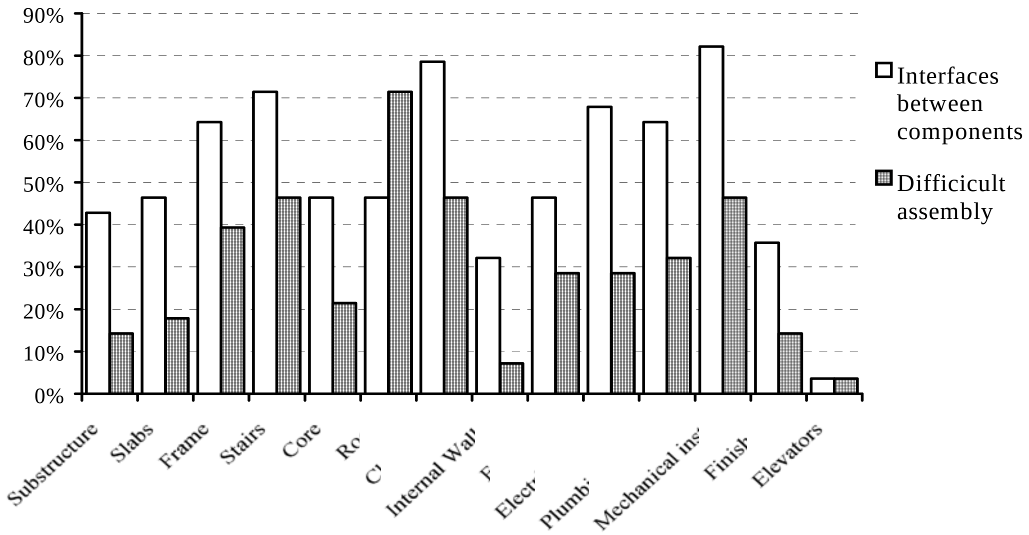

Figure 3: Buildability area problems

The contractor and consultant respondents, who had used visualisation in any one of its applications, realised the benefits that could be gained from the use of visualisation in construction. Therefore they thought that the use of visualisation would improve communication in construction.

FUTURE WORK

A study of the buildability problems will be carried out in depth by conducting case studies with several site teams. After the problems are studied in detail a proper visualisation and communication system will be developed. This system should allow for collaboration between design and construction teams in solving design problems that may occur during construction. The project's objectives were stated in the introduction of this report. Significant progress has been made on the first and the second objectives. Further work on the second objective will be carried out by conducting several case studies with a few of the industrial survey respondents to obtain more in-depth information about the problems that have been highlighted in the industrial survey.

Following the case studies, a survey and review of available software that can be used in the project will be carried out in order to allow the best one for achieving the aim of the project to be chosen.

Finally, the proposed system will be evaluated using test case from construction industry practitioners and further improvements made as necessary.

CONCLUSION

This research has set out a framework of an on-going research on the use visualisation to communicate design information during the construction stage. It discusses the buildability problems that may arise during the construction stage and how computer visualisation can play a key role in avoiding these problems. The aim and objectives of the research have been highlighted.

The research adopted two research methods: qualitative and quantitative approaches. A review of previous related works has been carried out and this revealed that only a meagre amount of works in the use of computer visualisation to communicate design information during the construction stage.

An industrial survey has been carried out using mailed questionnaire. The questionnaire was sent to the top 100 UK consultants and contractors based on turnover. The survey was about the use of visualisation tools and the buildability problems and how the information concerning these problems was communicated. The responses were analysed and they revealed that few construction organisations have used computer visualisation the design or construction stage. It also showed that the existing traditional methods of visualisation and communication were not adequate for dealing with buildability problems. These traditional tools were used in construction and the construction professionals used them because they were accustomed to them and reluctant to use any computer visualisation tools.

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