INFORMATION VISUALISATION IN CONSTRUCTION INDUSTRY; A QUALITY PERSPECTIVE

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The quality of information is highly dependent on the manner in which it is presented. Visualisation is one of the most important tools used to improve data presentation. However, construction companies generally have not gained full advantage of available visualisation tools since they do not consider such tools and techniques to bring significant improvement to their construction process.

This paper describes a research examining the quality perspective of visualisation, evaluating the use of visualisation tools and technology in construction projects. A survey is conducted in large and medium size AEC companies concerning the communication problems and the use of visualisation tools. Finally, a quality function deployment (QFD) approach is used for a combined evaluation of the research findings together with the customer needs and requirements expected from visualised information for project data communication.

Keywords: communication, quality, visualisation.

INTRODUCTION

Due to globalization of construction sector, construction projects increasingly utilize multinational, multi organizational, interdisciplinary partnerships, increasing the need for high quality and efficient communication alternatives. Parallel to this, visualisation is receiving increasing attention within the construction industry. However construction companies generally have not gained full advantage of the available visualization tools due to lack of sufficient experience and assistance in the successful implementation of the technologies.

The traditional approach to the construction process is similar to a relay race with the assumption that the project life cycle is divided into a series of sequential and separate operations undertaken by individual parties (Egan 1998). In this approach it is considered that each party is responsible for the assigned stage and does not have to pay attention to the previous or the following stages. This system seldom works out well due to the nature of the construction industry with unique, information-intensive projects requiring extensive co-ordination and communication between parties involved including all designers, engineers, constructors, suppliers, client etc. Conversely some firms have attempted to distance themselves from this method of operation and established improved cooperation of the parties in each operation through exploitation of IT (Information Technology) supporting a higher level of integration. The new technologies, adapted properly to construction sector, may reduce distances between geographically dispersed offices and form a continuous

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collaboration and cooperation link between the parties but it is observed in the industry that the firms generally fail in implementing the information technologies properly. Visualisation has been adapted to construction sector slower and at different intensity than many other sectors caused by the difficulties in the current communication methods used in construction The problem in construction sector is not a lack of technology but more a lack of awareness of how to exploit it and of how important major process and culture change is in order to allow this to happen [Betts and Ofori 1999].
Construction activities are carried out by many parties collaborating to successful completion of a project creating value to all involved. These parties are organizations with different size, location and capabilities that come together and collaborate for that specific project. If a computer environment is designed to facilitate the collaboration in such construction projects, contents, type and quality of the project information gains even more importance. Sharing information is critical in the success of construction projects but organisational and technical barriers reduce the quality, quantity, timeliness and accuracy of information flows [Sayar, 2000].

OBJECTIVES AND METHODOLOGY

This research is the continuation of [Nielsen and Erdogan 2003] and emphasizes the quality perspective of visualization, carried out in Turkish construction industry. The study maps out the industry's current IT and visualisation practices and extracts the extent of visualisation as a communication tool and the approach of AEC companies to new technologies. Focus of the study is the quality of visualized information, and the required level of visualisation in project specific websites.
The objectives of the research are the following:1) Conducting a literature review on visualisation in construction .2) Mapping out the industry's current IT and visualisation practices. 3) Estimating the extent of visualisation as a communication tool in the construction industry. 4) Evaluating the visualisation applications through a quality perspective put into action through QFD approach.5) Developing recommendations regarding the quality and level of visualisation in project communication.
The methodology included following tasks: 1) The current status of visualisation use in construction companies for communication purposes is mapped and the potential benefits to be gained through visualisation are discussed. 2) QFD methodology is reviewed and applied. 3) Status of visualisation use in project collaboration and the results obtained in the research are discussed.

THE ROLE OF VISUALISATION IN PROJECT INFORMATION EXCHANGE

Electronic communication can be viewed in 3 primary categories; communication, cooperation, and collaboration (Paul et. al. 2003). Phone, teleconferencing, fax and e-mail are the key technologies in the communication group.
Present computer technologies, such as electronic mail and Internet can substantially increase the amount and variety of project information communicated as compared to traditional manual methods [Zaneldin et. al. 2001]. Electronic mail, electronic bulletin board, network applications and web based communication systems are a few examples of electronic transfer.
Studying visualisation in construction is encouraged by a wish to improve both communication and information. The foreseen use of visualisation technologies are in

the cooperation and collaboration categories where project web sites, data sharing and virtual teaming are the key interaction technologies.
Another aspect in improvement of communication is improvement of quality of information. Quality of information has many aspects such as the conceptual view, data values (i.e. accuracy, completeness, consistency etc.), and representation (i.e. format and physical instances) [Redman, 1996]. Data quality can be a unique source of competitive advantage and construction companies aiming for sustainable competitiveness have to treat information as a strategic resource.
Project specific web sites and virtual teams are important steps towards eliminating unnecessary information transfer, offering easy access to required project information by using internet and web from any point around the world. Visualization technologies have potential to greatly improve communication and project teamwork. The type and appropriateness of visualisation technology is the main concern in producing the quality project information.
In this research the focus is on quality of visualised project data in construction sector; how to present data so as to achieve maximum comprehension within minimum time, and how to share and transfer those data to the other parties.

Current practices
The construction sector faces many problems and complexities due to the multi party character and geographically dispersed offices, which have to maintain continuous communication. The traditional separation of design from execution, the unique character of each project, and temporary teams specific to the project, are some of the challenges that may be solved by integration and interoperability. Here, communication plays the primary role. According to surveys conducted in Turkish construction sector, the chief problems of current practice are;

- Traditional approaches, resistance to changes and new technologies, fear of failure, resistance to novelty and cultural effect.
- Lack of integration and standardization; isolated teams and processes.
- Conflicting information due to lack of communication of design and model changes clearly and in time causing rework, increased budget and delays.
- Management practice and knowledge.

Quality of communication and information
The effectiveness of communication can be measured using critical communication variables; accuracy, procedures, barriers, understanding, timelines and completeness [Thomas et. al. 1998]. Luiten and Tolman (1997) state that the quality of communication is dependent firstly on the organisational changes, bridging the gap between design and construction information as well as between design and construction management stages, and secondly on a computer aided communication approach.
The complexities and problems of construction projects can be reduced by increasing the effectiveness, efficiency and quality of the communication through the introduction of the appropriate IT and visualisation tools.
Data quality can be a unique source of competitive advantage and construction companies have to treat information as a strategic source for the aims of sustainable competitive advantage.

In this research, data quality in construction sector is the issue of concern, and the focus is mainly on how to present data in order to provide maximum comprehension within minimum time and how to share and transfer those data to the other parties.

Visualisation technologies in project communication

Construction sector has adopted visualisation slower and at different levels of intensity compared to other industries, even though substantial academic efforts have been applied in the construction phase of the process. All of the companies examined in this survey use visualisation to varying extent defined by the company itself. Visualisation is considered by all to be a means of communication in which comprehension is simpler compared to other methods; however project design and contracting companies use visualisation in different ways. On examining their management techniques, methods and tools, the companies interviewed can be accepted as information age companies. As far as visualisation is concerned, the extent changes greatly from one company to another.

Design companies generally use visualisation tools in rather more sophisticated ways. They implement visualisation techniques in order to enable multidisciplinary communication, illustrate the completed state of the design and, to a limited extent, solve buildability problems.

The contracting companies approach visualisation from another perspective since the aim of a contracting company is rarely illustrating the final stage of a construction. However, contracting companies are required to show progress – completed jobs/total jobs – and also clarify method of construction.

PROBLEM STATEMENT

Visualisation is directly related with the quality of information, enhancing faster and easier human comprehension. In construction, a sector dealing with vast amounts of project information, there are various tools already in use or planned to be used. On the other hand these tools often fail to fully meet user requirements. Many tools are needlessly sophisticated or too advanced for normal use. In other instances graphical or visual means are unnecessary, such as in cases where the necessary information can be presented in one sentence of text. The problem is therefore to determine the level of visualisation required for meeting user requirements and expectations in view of priorities for each of the data flows that can be visualised in construction sector to a general extent. The aim is to attain a general solution that will generate an initial step for starting data and information improvement in terms of quality and presentation.

QFD APPLICATION FOR EVALUATING THE VISUALISATION USE

Quality Function Deployment (QFD)

The intention was to map out a relationship between user requirements and available technology. In this research the problem of information visualisation is approached using a QFD methodology, thereby mapping out linkages between user requirements for each information flow type with the technological possibilities that currently exist to the project participants.

QFD is a method for structured product planning and development that enables clear specification of the customer’s wants and needs, and then evaluation of each proposed product or service capability systematically in terms of its impact on meeting those needs [Cohen 1995]. The QFD process involves constructing one or more matrices through which the subjective customer perspective is converted to technical

characteristics. The most common matrices system is HOQ (House of Quality), taking its name from the shape of the combined matrices.
The QFD and HOQ are generally preferred 1) for constituting an effective way of translating voice of customer into technical characteristics, 2) due to its applicability to many areas, 3) for its versatile characteristics allowing modification of matrices in many different ways [ReVelle et.al 1998; Comstock and Dooley, 1998].

Methodology
The customer view is obtained through interviews, face-to-face meetings, and questionnaires conducted in 16 AEC companies and follow up phone calls in necessary circumstances. The interviewed companies are large scale companies working both domestically and abroad. They all have to maintain continuous communication in order to achieve collaboration and coordination between offices. The project managers or project coordinators of the companies are selected as the customer perspective representatives in view of the fact that they master the overall construction context and have an awareness of the information quality gaps in the communication. Whenever possible, IT managers or the head of the IT department are also interviewed in order to determine the current IT and visualisation applications of the company and appropriateness of possible means.
Data flows that can be visualised are extracted for further investigation of the appropriate visualisation level required.

Customer Requirements and Customer Perception
The general requirements and expectations of the companies regarding future visualisation and IT applications were determined during the interviews. The expectations obtained from all companies are organised to reflect WHATs corresponding to the general extent of the construction companies in Turkey. The expectations are listed in Table 1.

Table 1: WHATs / Customer Requirements

	EXPECTATION
1	easy to use
2	easy data transfer
3	Fast data transfer
4	easy access in remote areas
5	continuous communication
6	can clarify design details
7	can clarify construction methods
8	can give an idea of future work
9	allow multidisciplinary communication
10	increase comprehension
11	allow quick comprehension
12	no restriction to desktop working
13	check what if scenarios
14	help conflict resolution
15	allow online meeting

The interviewed companies were asked to evaluate the importance of each need. It was initially assumed that the customer needs and requirements' rank of importance would vary for each data flow, which was proved correct with the interviewees' comments. Therefore a matrix is prepared for the interviewees. Customer needs are

listed in the left and Data Flow types are listed on the top of this matrix and the customer perception is collected through these matrices.

The procedure of evaluating the customer perception through the matrix evaluations is explained below in a step wise manner.

- Interviewees evaluate the importance of each need for each data flow by entering L, M, H to the cells or leaving them empty or using 0 in order to imply that the need is not important or irrelevant to the data flow. The notations used in the matrix evaluation are shown in Table 2
- The values of L, M, H are replaced by 1, 3 and 5 respectively. The empty spaces have a value equal to 0.
- The values entered to the cells by each company are added up and divided by the number of interviewed companies. The values calculated are the average importance values of needs for each data flow.
- The average importance values of needs, calculated in the previous step, in the same column are summed up.
- The average importance values are normalised by dividing the overall importance value of their column. The relative importance total of the needs in the same data flow column becomes equal to 1 after this step (Table 3).

The values calculated through these steps provide the customer perception perspective. For example if the values in the Design Documents column are investigated it will be realised that the most important needs to be satisfied are better comprehension, quick comprehension, clarification of design details.

Table 2: Notations used in the matrix evaluation

Notation	Meaning	Assigned value
	Not important	0
L	Low	1
M	Medium	3
H	High	5

Visualisation tools satisfying customer needs

The customer needs are revealed through discussions with the interviewees. Likewise, they are asked to prioritise the needs for each data flow. As a result, the average normalised importance weights of needs are determined.

All visualisation tools have different characteristics causing variations in how and to what extent the customer needs are met. Considering the characteristics and capabilities of the visualisation tools, the effectiveness of each tool on the satisfaction of the customer needs are evaluated using L, M, H notations, which are assigned 1, 3 and 9 values, which are the most commonly used values in QFD approach. These values are used in this evaluation process to emphasize the strong relationships in order to determine the parameters to focus on during the design process. If the tool and the need are irrelevant, then 0 is used. The assessments are marked in a matrix where the visualisation tools are listed along the left and customer needs are listed along the top. For example, if the relevance between the need “can clarify design details” and 3D CAD drawings is considered, the impact is assessed as High since 3D CAD drawings have high presentation capabilities which create a 3D picture in the user’s mind quickly and explain all details visually. In contrast, the same need has no

relevance with daily/weekly/monthly report and therefore the relation is evaluated as 0. The matrix showing the evaluation of the degree of customer need satisfaction is given in Table 4.

Table 3: Customer needs vs data flow matrix: normalised average importance values

		DATA FLOW TYPES									
CUSTOMER NEEDS AND REQUIREMENTS	Customer Needs- Data Flow Matrix	Design Documents	Method statements	What if scenarios	Schedule-work Programme	Resource Planning	Progress report	Design Problems communication	Daily site records	RFI Request for info	Change order
	easy to develop	0.08	0.10	0.08	0.11	0.09	0.11	0.07	0.09	0.07	0.07
	electronic data transfer	0.08	0.05	0.08	0.06	0.07	0.07	0.06	0.06	0.08	0.08
	fast data transfer (with fast connection availability)	0.07	0.06	0.08	0.07	0.09	0.08	0.07	0.07	0.08	0.08
	easy access in remote ares	0.05	0.06	0.09	0.07	0.08	0.07	0.07	0.08	0.07	0.08
	continuous communication (min data transfer lag)	0.04	0.06	0.08	0.08	0.10	0.09	0.07	0.07	0.08	0.07
	can clarify design details	0.10	0.10	0.08	0.06	0.06	0.06	0.07	0.07	0.08	0.08
	can clarify construction methods	0.07	0.10	0.08	0.05	0.05	0.04	0.09	0.07	0.07	0.07
	suitable for conveying gained project experience to future projects	0.04	0.04	0.05	0.08	0.07	0.09	0.05	0.08	0.06	0.06
	allow mutidisciplinary communication	0.08	0.10	0.06	0.09	0.09	0.06	0.09	0.05	0.05	0.05
	better comprehension	0.10	0.10	0.05	0.08	0.07	0.08	0.06	0.07	0.08	0.08
	quick comprehension	0.10	0.07	0.08	0.06	0.06	0.06	0.08	0.07	0.10	0.10
	platform mobility	0.05	0.05	0.06	0.08	0.05	0.05	0.05	0.06	0.06	0.06
	check what if scenarios	0.03	0.03	0.05	0.06	0.06	0.06	0.05	0.04	0.05	0.05
	help conflict resolution	0.08	0.06	0.06	0.05	0.06	0.06	0.08	0.07	0.07	0.07
	possibility for online meeting	0.02	0.02	0.03	0.02	0.02	0.02	0.05	0.04	0.04	0.04

Table 4: Tools vs Needs Matrix (L=1, M=3, H=9)

		NEEDS															
TOOLS	HOW MUCH DOES THE TOOL SATISFY THE CUSTOMER NEEDS?	easy to develop	electronic data transfer	fast data transfer (with fast connection availibility)	easy access in remote ares	continuous communication (min data transfer lag)	can clarify design details	can clarify construction methods	suitable for conveying gained project experience to future projects	allow mutidisciplinary communication	better comprehension	quick comprehension	platform mobility	check what if scenarios	help conflict resolution	possibility for online meeting	
	2D CAD drawings	H	H	H	M	H	M	M	H	M	M	M	H	M	M	H	
	3D CAD drawings	M	H	H	M	H	H	H	H	H	H	H	H	H	H	H	
	2D Graphics, Charts	H	0	0	L	0	M	M	H	M	L	L	L	0	M	0	
	3D Graphics, Charts, Virtual photographs (3D Studio, studio max)	M	H	H	M	H	H	H	H	H	H	H	H	H	H	H	
	Tables	H	H	H	M	H	M	0	H	L	L	L	H	M	L	H	
	Photographs	H	0	0	L	0	H	M	H	H	M	M	M	0	M	0	
	Digital photographs	H	L	H	M	H	H	M	H	H	M	M	H	0	M	H	
	Virtual Reality	L	M	M	L	M	H	H	H	H	H	H	M	H	H	M	
	Walkthrough	M	M	M	M	M	M	M	H	H	H	H	M	0	M	M	
	Video	H	L	H	M	M	M	H	H	H	H	H	H	0	H	H	
	Animation	M	L	H	M	M	M	H	H	H	H	H	H	H	H	H	
	Simulation	L	M	H	M	L	L	H	M	H	H	H	H	H	H	H	
	Steady images	H	0	H	M	H	M	M	H	H	H	H	H	0	H	H	
	Text Documents	H	H	H	M	H	M	L	H	H	L	L	H	0	L	H	
	Daily/Weekly/ Monthly Reports (on paper)	H	0	0	0	0	0	0	H	M	L	L	L	0	M	0	

Need satisfaction values

The interviewees have determined the importance of the needs. The product of these importance values and the need satisfaction values gives the weighted impact of the visualisation tool on satisfying the needs.

The sum of these weighted impacts termed the Need Satisfaction Value. This value represents the capability of the visualisation tool to satisfy the needs defined by the customer according to the prioritisation, reflecting the customer's perspective, of the needs. Since the prioritisations of needs differ for each data flow this procedure is repeated for each data flow. The calculated values for all data flows are shown in Table 5.

Table 5: Need Satisfaction Values tools for each data flow

HOW MUCH DOES THE TOOL SATISFY THE CUSTOMER NEEDS?		NEEDS									
		Design Documents	Method statements	What if scenarios	Schedule-work Programme	Resource Planning	Progress report	Design Problems communication	Daily site records	RFI Request for info	Change order
TOOLS	2D CAD drawings	5.02	5.09	5.49	5.78	5.71	5.88	5.21	5.62	5.40	5.34
	3D CAD drawings	**7.61**	**7.64**	**7.58**	**7.59**	**7.65**	**7.58**	**7.65**	**7.57**	**7.58**	**7.52**
	2D Graphics, Charts	3.19	3.18	2.88	3.13	2.93	3.13	2.98	3.16	3.01	3.02
	3D Graphics, Charts, Virtual photographs	**7.40**	**7.50**	**7.43**	**7.47**	**7.53**	**7.47**	**7.49**	**7.42**	**7.37**	**7.31**
	Tables	4.92	4.58	5.34	5.58	5.47	5.69	4.97	5.45	5.52	5.46
	Photographs	3.14	3.53	2.90	3.48	3.22	3.29	3.14	3.15	2.73	2.74
	Digital photographs	5.06	5.38	5.33	5.78	5.71	5.64	5.38	5.52	5.24	5.18
	Virtual Reality	5.76	5.88	5.32	5.38	5.39	5.34	5.66	5.40	5.35	5.33
	Walkthrough	4.86	4.76	4.32	4.61	4.56	4.53	4.54	4.49	4.56	4.56
	Video	**7.51**	**7.60**	6.95	7.05	6.94	6.90	**7.23**	**7.23**	**7.11**	**7.11**
	Animation	7.35	7.27	6.98	6.96	6.90	6.81	**7.26**	7.07	**7.14**	**7.14**
	Simulation	6.99	6.80	6.51	6.27	6.24	6.05	6.80	6.41	6.67	6.69
	Steady images	6.71	6.70	6.42	6.83	6.79	6.76	6.63	6.73	6.64	6.58
	Text Documents	5.60	5.48	5.85	6.20	6.11	6.10	5.72	5.88	5.90	5.84
	Daily/Weekly/ Monthly Reports (on paper)	1.82	1.97	1.74	2.26	2.05	2.29	1.81	2.07	1.69	1.69

DISCUSSION OF RESULTS AND CONCLUSION

The customer needs and requirements are investigated by interviews organised with managers of construction companies. The interviewees are asked to set importance weights to their perceived needs.

Using the QFD approach and the matrices, the voice of customer is converted into technical specifications, which in this research are applied to visualisation tools. The final outputs of this approach are the need satisfaction values obtained for each visualisation tool for each data flow. The final values are given in Table 5, and notable values are listed in bold figures.

The general tendency of the optimum seems to be 3D CAD drawings, 3D graphics, charts, virtual photographs, videos and animations. This is not surprising since the customers' importance of need evaluations came up as high averages for the needs such as; easy to develop, better comprehension, quick comprehension, clarification of

methods and design details, relatively higher than the other tools. Since the visualisation tools, 3D CAD, graphics, videos, and animations have these advantages, both the weighted averages and the rated satisfaction values have yield a high Need Satisfaction Values of these particular tools. Therefore the degree of visualisation tools usage should be in accordance with the rank of need satisfaction values.
Although the qualitative approach yields an optimum level through rating techniques and matrix evaluation, the visualisation tool highlighted as the optimum is not necessarily the optimum solution for that data flow since each visualisation tool has specific characteristics and offers varying solutions to different problems. But it provides a prioritisation of the technical characteristics, visualisation tools, to be used in order to achieve the customer needs ranked according to the customer importance weights. It can not be stated that, for example, since the highest need satisfaction value for the schedule and work programme data flow is 3D CAD drawings, starting to use or increasing the use of 3D CAD drawings in this data flow will solve all the problems and the optimum visualisation level will be achieved. But it can be said that to achieve the needs defined within the rank provided by the customer, the visualisation tools to be used should be ranked according to the need satisfaction values.
Visualisation tools may have totally different characteristics. On the other hand, a group of tools may have similar characteristics but may have unique features, which may make one of them the only solution for a particular task. In some situations a particular tool may be the unique solution for a task. In other situations, there may be tools with similar functions where we may choose the most suitable.
Although rating techniques of QFD are applied to convert the qualitative characteristics into quantitative characteristics, subjectivity is still in the matrices. The subjectivity of the companies is understandable since there is no way that precise metrics can be applied in an attempt to re-shape the manner which information is conveyed. Oppositely it is argued that the optimum tool selection must be based on the decisions and evaluations of each company on its own. Furthermore, projects are unique and level of implementation of visualisation tools must be considered project-specific, for reasons of cost-intensity, type (special engineering or standard construction works), and so on.
In this study an attempt was made to map linkages between user requirements for various information flow types in construction with the visualisation technology currently available to participants of the construction process. In the light of visualisation being a very efficient way of conveying information to human beings, the aim was to relate construction practitioner's requirements to the abilities of available tools.
A general application of the QFD method is provided. An overview is presented of what is entailed in QFD as a background to assessing levels for visualised information in the construction process. In most cases, however, a QFD approach in this area would rather involve one individual company.

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