K7

ICT-SUPPORTED COLLABORATIVE WORKING IN CONSTRUCTION

Geoffrey Qiping Shen

Chair Professor of Construction Management, Department of Building and Real Estate,
The Hong Kong Polytechnic University, Hong Kong
Correspond to bsqpshen@polyu.edu.hk

ABSTRACT: This paper explores the ways in which collaborative working among multiple disciplines in building projects can be more effective and efficient. It focuses on the support that can be provided by the latest development in information and communication technologies. It also considers the growing interdependence between participants in the process and their changing roles as they harness the power of the new technologies in new collaborative arrangements. It is argued that collaborative working should be addressed holistically from the technological angle, the social angle, as well as the organisational angle, to ensure its successful implementation in the construction industry. A case study is given to illustrate the use of ICT in supporting value management studies. The key issues surrounding the emerging field of research - collaborative construction information management - and the potential benefits and challenges of its wide adoption are discussed at depth.

Keywords: Collaborative Working; Construction; ICT

1. INTRODUCTION

Compared to other industries, labour productivity in the US construction industry has declined since 1964 (Teicholz, 2004). One of the main reasons for the lack of progress in productivity is the fragmentation in the construction industry, which is dominated by small and medium sized organisations, and further complicated by the applications of isolated technical solutions and the lack of interoperability of design tools. It is widely accepted that to overcome productivity problems organisations need to work collaboratively to address the communication and information exchange problems in the industry. There are a number of other drivers for improved collaboration among stakeholders working in the construction industry such as the effectiveness of organisational operation, the need for more efficient use of resources, and the desire to accomplish more than what is possible through reductionist approaches where sub-optimisation are developed, i.e. to make the whole greater than the sum of parts.

Collaboration is, however, a highly complex and challenging task, which can be defined as 'the agreement among stakeholders to share their abilities in a particular process, and to achieve the objectives of the project' (Kalay, 1998), i.e., two or more stakeholders share their efforts and resources in a particular way, in order to achieve their common objectives.

This paper reviews collaborative working and related Information and Communication Technologies (ICT) in the construction industry. It highlights the key aspects of using ICT to support collaborative working and the contributions of the leading researchers in this field. It also introduces a new research area - collaborative construction information management, which focuses on collaborative, integrative and multidisciplinary team of stakeholders to tackle complex multi-scale issues involved in creating viable solutions in the context of the built environment.

2. COMPUTER-SUPPORTED COLLABORATIVE WORKING IN CONSTRUCTION

Collaboration is widely interpreted as working in unison, which denotes a more durable and persuasive relationship. It includes "user communication and user awareness of each other's actions" (Shelbourn et al., 2005). It is "…two or more companies working jointly to: share common information; plan their work content based on that shared information; and execute with greater success than when acting independently" (Barthelmess, 2003). It is "a philosophy of interaction and personal lifestyle and cooperation as a structure of interaction designed to facilitate accomplishment of an end product or goal through people working together in groups" (Attaran & Attaran, 2002).

Collaborative working in construction means joint efforts among major project stakeholders to complete a construction project effectively and efficiently. It covers a wide spectrum of ways that two or more organizations can work together. Options range from informal networks, alliances or partnering to full integration. It can last for a fixed length of time or can form a permanent arrangement.

In 1984, Irene Greif of MIT and Paul Cashman of Digital Equipment Cooperation organized a workshop attended by individuals interested in using technology to support people in their work. During this workshop, the term 'Computer Supported Cooperative Working' (CSCW) was first coined to describe work supported by computer technology (Grudin, 1994). It is an effort by technologists to learn from economists, psychologist, anthropologists, organizational theorists, educators, and anyone else who could shed light on two main concerns relevant to group activities: how technology can be used to support people's work and how people work in this technology-supported environment (Grudin, 1994). The word 'collaborative' has replaced 'cooperative' subsequently, and 'computer supported collaborative working' occurred to recognise the growing importance of information and communication technologies in collaboration. The word 'collaboration' includes all aspects of technology, organisation, human factors, and the need for a holistic approach.

There has been considerable research into CSCW since 1984, focusing on both supporting technologies and human and organisational aspects of their adoption. The focus was on "the use of computer technologies to support collaborative activities, as well as the impact of digital collaboration technologies on users, groups, organizations and society" (Greif, 1998).

The advent of computing technologies has resulted in different modes of collaborative working. Anumba et al. (2002) describe modes of collaboration based on a classification of space and time, as shown in Table 1. Typical forms of collaboration in space and time are also described by Attaran & Attaran (2002).

Table 1 Collaboration Models (Anumba et al., 2002)

	Same time	Different Time
Same Place	Face-to Face Collaboration	Asynchronous Collaboration
Different Place	Synchronous Distributed Collaboration	Asynchronous Distributed Collaboration

Face-to-face collaboration denotes to meetings in a common venue and participants engage in face-to-face discussions. Asynchronous collaboration means that activities take place at different times but in the same location. This mode of collaboration can be conducted using medium such as notice/bulletin boards within an organization. Synchronous distributed collaboration involves activities that take place at the same time with participants located at different places. Asynchronous distributed collaboration refers to activities which take place at different places at different times. This mode involves communication via the post e.g. periodic letters/news bulletins, fax machines, telex, voice mail, pagers, electronic mail transmissions, etc.

Regardless the mode of communication between the parties within the project, it is essential that all parties are provided with updated, accurate information on which to base their decisions. Collaboration has been facilitated by technologies, which have changed as new technologies have emerged to supplement and replace those that already exist.

There are a number of software packages available to facilitate collaborative working in general. Groupware, for example, is a name given to application software developed to support the collaboration of several users (Dix et al., 1998). The interfaces between computers and end users have been consolidated and web-based collaboration systems have emerged, which is a very effective medium to conduct design reviews and offers many benefits over traditional manual methods of comment collection and resolution (East et al., 2004).

The increasing importance of collaborative working is also highlighted in several recent reports. European Commission

Information Society and Media (2006), for example, believes that in the constantly changing global economy, the ability to communicate over time and space, within and between organisations or communities, is essential to successful operations of business. Collaborative environments are necessary to increase the productivity as well as the creativity by enabling new forms of working in production and knowledge intensive businesses. In the findings of a major EU research project which looked at perspectives of mobile and collaborative working, Scaffers et al. (2006) argue that "the way in which we are organising our work has changed considerably over the past 20 years and will continue to do so in the future". On the future of collaborative working, they stress that it is not just a matter of technology, it includes other key issues such as cross-organisational cooperation, management and leadership, organisational structure, business models, and incentive schemes etc..

3. INTERACTIVE VALUE MANAGEMENT SYSTEM – A CASE STUDY

One of the frequently-used tools used to support collaborative working in the construction industry is Value Management (VM). By definition, VM is a function-oriented, systematic team approach to provide value in a product, system or service (SAVE International, 1998). As shown in Fig. 1, it is one of the widely-used tools to harness the creative powers of a group of people to achieve more than the sum total of each contribution. The process uses structured, team-oriented exercises that make explicit and appraise existing or generated solutions to a problem, by reference to the value requirement of the client (Male et al., 1998). The implementation of VM in a construction project is normally in the form of one or more workshops, which are attended by the major stakeholders, facilitated by a value specialist, and follow a "systematic job plan".

A group support system (GSS) is an interactive computer-based information system which combines the capabilities of communication technologies, database technologies, computer technologies, and decision technologies to support the identification, analysis, formulation, evaluation, and solution of semi-structured or unstructured problems by a group in a user-friendly computing environment. As there is a demand for improving the practice of VM, research has been conducted to design a GSS prototype, Interactive Value Management System (IVMS), to explore its potential application in VM studies and to investigate the effect of the application.

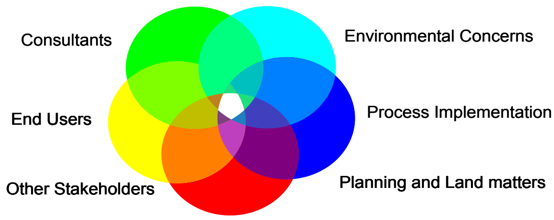

Fig. 1 Collaborative Overlap of Key Stakeholders

Design of IVMS

IVMS aims to supply a useful toolbox which can support VM practitioners to overcome the problems in traditional VM workshops. Another concern is to build a computerized project database that contains various types of projects, which can be used as references for similar projects. It should be stressed again that IVMS is designed not to replace traditional VM procedures but to act as a beneficial complement by providing technical features. The system can be used by a team who are geographically remote or integrated with the traditional face-to-face method to exploit the full benefits of both modes of communication.

IVMS is built based on the Windows SharePoint Services (WSS) from Microsoft, which serves as a platform for the development of the application. Microsoft Windows Server 2003 is adopted as the Operating System, and Microsoft SQL server, which supports concurrent data access, is adopted as Database Management System. Microsoft Visual Studio. Net 2003 is used as the development environment of the application system. The system is coded mainly by using ASP.NET, C# and JavaScript.

Including such functions as team workspaces, e-mail, presence, and web-based conferencing, WSS enables users to locate distributed information quickly and efficiently, and work with others more productively. With the help of WSS, IVMS can be easily integrated with other useful software, including Microsoft Visio, Office and Messenger. Based on the characteristics of VM workshops and the features of GSS, the system structure of IVMS is designed, as shown in Fig. 2.

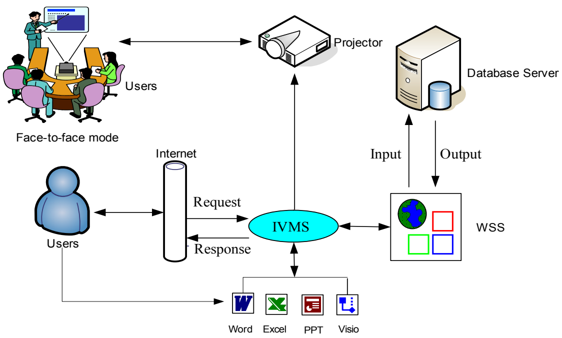

Fig. 2 System Architecture of IVMS

Use of IVMS to Support VM Studies

IVMS is designed to facilitate information management, improve communication and assist decision analysis in the VM workshops. Although there are various application procedures at different stages of the project, all of them are more or less following the standard VM job plan. Male et al. (1998) gave a generic VM process in their benchmark study for VM. Fig. 3 illustrates the process and outlines the steps. The steps where IVMS can be used are marked with asterisk (*). The following part will illustrate the use of IVMS in VM workshops in details.

Pre-Workshop Phase

The pre-workshop phase provides an opportunity for all parties to understand project issues and constraints before the workshops. As mentioned previously, one of the main problems in VM studies is poorly organized information and difficulty in retrieving project information in workshops. In order to overcome these problems, several tools are provided, including:

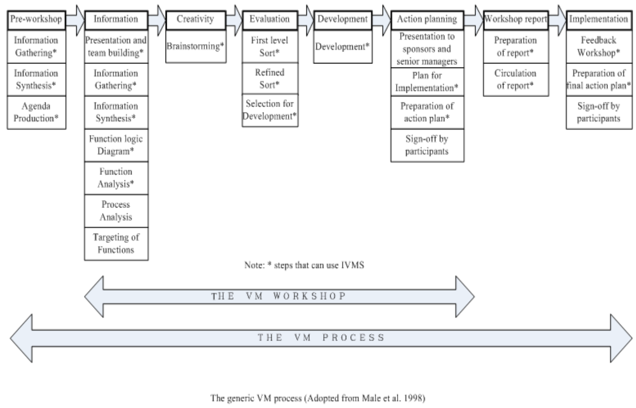

Fig.3 The Generic VM Process (Male et al., 1998)

- A document library for users to store and share project information, with features such as version history, permission management, email alert, full-text search capability, and view selection.
- A bulletin board for users to disseminate and discuss ideas, to ensure that major stakeholders involved in the project understands the issues and constraints.
- A questionnaire survey for the participants to raise strategic and tactical issues surrounding the project.
- An electronic agenda provides an outline of the workshop including details of those who will lead the discussion on each subject, and the time allotted.
- These features improve the efficiency of information sharing, enhance information circulation, and enable workshop facilitators to computerise and centralise information gathering, distribution and circulation processes throughout VM studies.

Information Phase

In this phase, information relating to the project under review (e.g. costs, drawings, specifications, and samples) needs to be collected (Kelly et al., 2004). The objective is to identify, in clear terms, the issues of the whole or parts of the projects, as seen by the client organization (Male et al., 1998). A VM workshop is commonly held in a conference room, a semi-closed environment with physical boundaries which may prohibit the users from retrieving any new information during workshops. The connection to the Internet breaks the physical boundaries of the conference room and allows members to access external information easily during the workshop. To utilise this web-based feature, a database is provided to facilitate users in searching for relevant information. The “Document Library” also plays an important part in the process of retrieving information as all the information related to the VM workshops can be stored in the system before the workshop. Files can be shown on a large common screen or members’ terminals, making the process of reviewing data more efficient.

Function Analysis Phase

The function analysis phase aims to clearly define functions and the requirements of the project. All functions are expressed as an active verb plus a descriptive noun. The system provides support to the users by providing

Virtual Meeting Rooms. According to different situations, the environment of these rooms can be switched between anonymous and nominal mode. In both modes, users can see all the functions that have been generated by others on their own computer, so users may spur each other in generating functions. The functions are stored automatically in the system as generated. Compared to recording the generated functions on the paper in the traditional way, this feature can save much time. Following the generation of functions, the VM team is invited to rearrange the functions by putting the highest order need at the far left side and the lowest order want at the far right side. Some commonly used software, such as Microsoft Visio and Excel, can be used to integrate with the system to provide models tools.

Creativity Phase

The main task of this session is to generate numerous alternatives for accomplishing basic functions required by the clients, by means of creativity techniques. Brainstorming is the most popular technique in the creativity phase. It requires that users consider a function and contribute ideas which expand, clarify or answer that function. However, due to the large number of participants and some of them are reluctant to speak out in this phase because they are shy of speaking in public or afraid of being criticized or sounding stupid. The process can also be dominated by a few individuals, and make the creativity process very unproductive (Mullen et al., 1991; Camacho and Paulus, 1995).

To overcome these communication problems, the system provides Virtual Meeting Rooms, which are similar to "chat rooms" on the Internet. One of the basic rules of the brainstorming process is that the group should be relatively small. However, there can be 20-30 stakeholders in a VM workshop, in which case members are assigned to five "rooms" in the system. Workshop members "go" to the assigned room and submit their ideas. The main features of these virtual rooms include:

- Switch between anonymous and nominal mode. The environment can be set to be anonymous or nominal according to the need of the workshops. When the environment is anonymous, each user can read on his or her screen the ideas generated by other group members without knowing from whom they originate. Users who fear receiving negative comments from others in the face-to-face session may appreciate the environment of anonymity in IVMS.
- Brainstorming agent. This agent can pop-up with different words and gestures which are corresponding to situations. The agent "monitors" the performance of both the whole group and individuals based on criteria such as quantity of ideas generated, idea generation rate, and percentage of participants in the group who are active in generating ideas.
- Control functions for the facilitator. These functions are provided to the facilitator including changing the environment mode, editing/deleting unnecessary ideas, posting notices. This setting enables the facilitator to control the VM process.
- Tips for generating more ideas. This function is designed to provide constructive suggestions to the users. The aim is to provide "triggers" so that participants can think in a different way.
- Enabled parallelism in idea generation. Parallelism helps reduce production blocking since users no longer have to wait for others to express their ideas (Gallupe et al., 1991; Jessup et al., 1990).

Fig. 4 VM Study with IVMS Support

Evaluation Phase

According to SAVE International (1998), the main tasks in this phase include: setting up criteria, and evaluating and selecting alternatives. We have used weighted evaluation technique in this phase.

- Idea categorization: Ideas will be collected and listed in respect of each function. The facilitator can delete overlapping ideas and correct grammar or spelling mistakes. These ideas will then be classified by the workshop participants into different categories.

- Weighted evaluation: This step includes three tasks: list criteria, assign weighting, and score ideas. They are explained in the following three paragraphs.

Development Phase

In this phase selected alternatives are investigated in sufficient depth, such that they can be written into recommendations for implementation. This involves not only detailed technical and economic evaluation but also applicability for implementation. The document library can be used to make the presentation process more flexible and effective. Users can upload the files to the document library, and others can view them. When sub-groups have been formed to develop ideas the system is more useful, for the reports of each group can be collected and shared quickly through the document library. The system also facilitates the preparation of an action plan, by providing task management functionality such as Gantt charts for visualization of task relationships and status.

Reporting and Implementation Phase

The objective of implementation is to assure the proper implementation of the approved value study change recommendations and collect feedback on the proposal. A detailed report must be prepared as soon as possible after the workshop. Since the system can automatically collect the main information of the workshop, such as the quantity of the ideas, the time of each phase of the workshop etc., it will be helpful to the preparation of the workshop report. The document library can also be used to circulate the report. The information collected also could be used to evaluate the processes and outcomes of the workshop. There is also a questionnaire at the end of the workshop to collect users' views on the workshop. The system provides several efficient ways to collect feedback, such as bulletin board, questionnaires and notice board. Through these functions, users can conduct online discussions, post their ideas, and submit their feedback whenever they like through the Internet.

Summary of research findings

The case study described in above is unique in its investigation of the effectiveness of using GSS in VM workshops. Although the research studies are limited to a laboratory setting, they influence the direction of future field studies. The results show that web-based GSS can improve the efficiency and effectiveness of VM workshops by supporting the VM team. The result of the validation of the system shows that IVMS is a useful tool in facilitating the information exchange process, encouraging interaction, and promoting active participation in VM workshops. It also reveals that web-based GSS can overcome some of the common problems identified in VM workshops.

4. COLLABORATIVE CONSTRUCTION INFORMATION MANAGEMENT

Research Issues of CCIM

Design for the built environment is seen as one of the multidisciplinary practices in all design professions, since many professions are required to work closely during the design phase. Collaboration among different participants in the design of a building involves both synchronous and asynchronous communication. The different participants require the ability to work on their part of the project using their own particular ways of working yet being able to communicate with the other participants to bring about a common objective, the design of the building.

Collaborative Construction Information Management (CCIM) is a new research area which focuses on how to support and facilitate collaboration and integration between multidisciplinary stakeholders to tackle complex issues involved in creating viable human futures in the context of the built environment. It aims at addressing major problems in the construction industry: fragmentation, isolated technical solutions, and interoperability of design tools. The ultimate goal of collaboration is to improve productivity and enable innovation through empowered and motivated people. The primary drivers for collaboration in the industry include effectiveness of organisational operation, need for more efficient use of resources, and accomplish more than it would have independently.

To further investigate the key issues, problems, the potential benefits and challenges in this new research area, we have organised an "international workshop on collaborative human futures - a new design paradigm" in November 2007, attended by more than 20 leading experts in the field from the USA, the UK, France, Australia, Finland, and Hong Kong. Collectively we have explored the key issues the research problems surrounding collaborative information management in construction. As shown in Fig. 5, we have identified three broad areas of research: technological, social, and organisational, each of them aims to address the problems we encounter from a specific dimension. A large number of research issues and relevant projects have been identified under each of the three dimensions, they are also widely reported in the leading journals in the building and construction field such as:

- Building Research and Information,
- Journal of Construction Eng. and Management,
- Automation in Construction,
- Journal of Management in Engineering,
- Construction Management and Economics,
- International Journal of Project Management, and
- Eng., Construction and Architectural Management

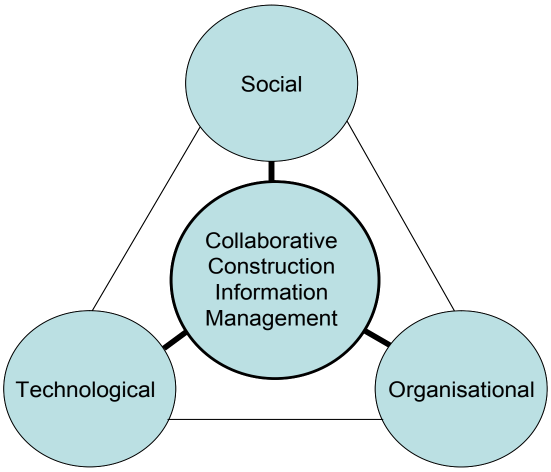

Fig. 5 Dimensions in Collaborative Working

Research works relevant to the technological aspects of CCIM includes:

- 3D virtual environment for different designers
- Agent and multi-agent approach
- Artificial intelligence, multi-agent, web technology
- Building information modelling (BIM)
- Client-server architecture, web-based technology
- Client-server Internet-based collaborative design
- Collaborative scheduling
- Collaborative virtual organization-contractor
- Component-based open architecture
- Computer-supported collaborative working (CSCW)
- Construction (project) management system
- Design review through web collaboration
- IFC-based collaborative construction environment
- Integrated production scheduler (JAVA and XML)
- Integrated technical information service (CITIS)
- Integration of inter-organizational information
- Mixed reality-based visualization interfaces
- nD modeling
- Virtual reality (VR) and virtual prototyping
- Wireless technologies: on-site data collection

Research works relevant to the organisational aspects of CCIM includes:

- Complexity and social setting
- Definition and framework for coordination
- Effect of cultural differences
- Factors inducing knowledge creation
- Hard and soft elements
- Joint venture
- Knowledge management
- Knowledge sharing and delivery innovation
- Learning organization culture
- Mobilization of partners
- Owner-contractor relationships
- Partnering
- Project alliance and strategic alliance
- Public-private partnership (PPP)
- Relational contracting (RC)
- Supply chain management
- Value management

Research works relevant to the social aspects of CCIM includes:

- Behavioural management mechanism
- Collaborative work environments
- Communication
- Critical trust factors
- Collaborative work arrangements
- Financial incentive within project coalition
- Interaction between workplace and human behaviour
- Issue resolution mechanism
- Relationship management
- Tension and conflict

- Trust and confidence as measures
- Trust and mistrust

Benefits and Challenges

We are experiencing a major change in the design and construction of building projects. ICT-supported collaborative working emerged in the last decade has reached a point where they may now be considered as the recognised platform for the design and construction of many construction projects. Their adoption has reached 'the tipping point' whereby their use may grow significantly in the next decade (Brandon et al., 2005). Whereas the focus of the industry in the last decade has been the processes of design and construction and a more efficient and effective procurement whereby the number of interfaces and the enormous overhead of communication have been reduced by technology We are seeing clients demanding their professional teams use 3D models and collaborative environments are created to minimise interfaces through automation and collaborative working (Brandon, 2007).

CCIM will improve productivity and reduce waste within the construction process; change the role of professionals within the process and when and how they contribute their knowledge and expertise, enable data on individual projects to be shared within other larger models of the built environment, re-engineer existing business processes, and require new types of software and new technologies. Their introduction will only succeed however if the 'soft' aspects of systems and their implementation into organisations is considered, understood and taken into account.

The applications of CCIM will bring many radical changes to the way that architects and other relevant professionals work on building projects (Kiveniemi and Fischer, 2007). The extensive use of digital technologies and computational design environments, for example, has resulted in highly non-linear and dynamic interactions between the design and production processes which in turn leads to emergence of a new, cross-disciplinary, and collective body of design knowledge, built collaboratively by various parties taking part in the design and implementation processes (Kocaturk, 2007).

Building Information Modelling (BIM) and related technologies, for example, will fundamentally change the project value chain. They will present a new virtual future for design, construction and procurement. They will change how participants collaborate, when the project participants collaborate and the contractual basis under which they participate. The opportunities offered by these new technologies will result in the need for all businesses to review and refocus how they add value to design and construction within this new business environment. They will also change the nature and timing of how design proceeds and how and when client value is added within the design and construction process (Brandon and Kocaturk, 2008).

BIM is defined as a modelling technology and associated set of procedures to produce, communicate and analyse building models, which are intelligent digital representations of building components, which include data to describe how they behave (Eastman et al., 2008). These data are consistent and non-redundant and may be combined in such a way that the model may be represented in a coordinated way.

IFC (Industry Foundation Classes or "Information for Construction") schema defines a standardized file format that can be used as a mechanism for sharing semantically rich building information between CAD systems and an ever-expanding range of design analysis tools (Plume and Mitchell, 2007). According to Fisher and Kam (2002), who used IFC technology to facilitate data exchange among the major design partners in the project, these relatively seamless data exchange and technology tools substantially expedited design and improved the quality of interdisciplinary collaboration.

Virtual Reality (VR) is another technology which may have profound impact on collaborative working. VR has the ability to model and visualise both the design and the construction process thereby facilitating collaboration between all parties within the process. It is possible for a multidisciplinary design team to use a virtual world platform and a model for representing the design from the perspectives of different disciplines, within which views of the various disciplines are modelled in separate hierarchies and the relationships between the various models are specified (Rosenman et al., 2007). One of the main advantages of a virtual environment is that it allows users to be immersed in it, allowing for real-time walkthroughs and collaboration (Savioja et al., 2003). The environment also facilitates synchronous communication and modification to the designs of different disciplines. Riese (2007) and Li et al. (2008) have given examples to demonstrate how design and construction can be integrated through virtual prototyping.

The overriding factor that will ensure the successful adoption of CCIM within design and construction is increased client value. "Cost estimation integrated with a BIM design tool allows designers to carry out value engineering studies as they design, and make the best use of client's resources". This kind of incremental VM studies allows improvement throughout the design. It may revolutionise VM and the collaborative working of parties to ensure that the construction client achieves maximum value from the new building (Eastman et al., 2008). The use of 3D computer visualisation in VM studies can be a very promising area of research. Male (2007) demonstrated on how the requirement for such methods has arisen and possible ways of using such solutions by large volume procuring clients, the large contractors and consultants.

Whilst the potential benefits of using CCIM and related technologies are increasingly apparent, the barriers and challenges to its wide adoption are also increasingly clear. These challenges include, but not limited to, changing roles in teams, changes in practice and use of information, implementation issues, and legal issues related to documentation ownership and production (Eastman et al., 2008). For example, there is still no overall integration scheme for sharing of information between the existing tools (Obonyo and Anumba, 2007). The challenge of seamless data interchange between different software packages, i.e., interoperability, is probably the major barrier to the widespread adoption of BIM (Godfreid, 2007).

For service-based operations such as construction, effective collaborative working will not be achieved through people working slavishly in their professional disciplines that only serve to impede the process, but through the adoption of new roles that recognise the needs of new working practices" (Bacon, 2007). "When people work together systematically using integrated processes, sharing common data, seamlessly exchanged between heterogeneous systems, an efficient and effective service is likely to be the outcome."

5. CONCLUSIONS

Although the concept of ICT-supported collaborative working has been in existence for some time, only until recently, it started to attract increasing attention from the building and construction industry. Three major and interrelated aspects in collaborative working have been discussed in this paper. A number of research issues have been identified from each of the three aspects. A case study on how collaborative working among major stakeholders can be supported by the use of ICT. It has demonstrated its applicability and success in addressing the unique problems existed in our industry.

The advent of collaborative information management and related technologies represent a new way of working that will become widely adopted throughout the construction industry over the next 15-20 years. This new way of working is now being embraced by large clients, designers and construction organisations world-wide. It offers a new platform for information management and a new basis for collaborative working, and has the potential to revolutionise the construction industry in the next few decades.

These technologies, methods and approaches provide the catalyst for change and begin to change the nature and form of the design and construction process. The new technologies will change the roles of the participants and it will be some time before this can be assessed as this is an evolving process. As this form of collaborative working develops, we need to consider issues such as 'democratisation' of design; changes in the power of the community; and collaborative working in its widest sense whereby all the stakeholders are actively engaged in the design process.

There are many challenges ahead which will require close collaboration among participants of construction projects, supported by the latest development of ICT. This paper represents the views of both academics and practitioners working in the filed. It is anticipated that these insights will provide an indication of the direction the industry might follow. It is also important that the discussion continues if the construction industry is to emerge as an efficient and effective force for the development of human activity and environment.

ACKNOWLEDGEMENT

The authors wish to express their sincere gratitude to the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Ref No. 5114/03, 5161/04, 5252/05, 5264/06) for the generous funding support to the projects on which this paper is based.

REFERENCES

Anumba, C.J., Ugwu, O.O., Newnham, L., and Thorpe, A. (2002). Collaborative design of structures using intelligent agents. Automation in Construction, 11(1), 89-103.

Attaran, M., and Attaran, S. (2002). Collaborative computing technology: the hot new managing tool. Team Performance Management, 8(1/2), 13-20.

Augenbroe, G. (2007). Applying process rigor to the use of BIM in building design teams - A review of three technologies, Proceedings of the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 12-27.

Bacon, M. (2007). A data centric process orientated model for effective collaborative working, Proceedings of the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 28-33.

Barthelmess, P. (2003). Collaboration and coordination in process-centered software development environments: a review of the literature. Information and Software Technology, 45, 911-928.

Brandon, P.S. (2007). Collaboration: a Technical or Human Interface Problem? Presentation at the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November.

Brandon, P., Li, H., and Shen, Q.P. (2005). Construction IT and the 'tipping point'. Automation in Construction, 14 (3), 281-286.

Brandon, P.S. and Kocaturk T. (Eds) (2008). Virtual Futures for Design, Construction and Procurement, Blackwell Publishing, Oxford, England, ISBN 978-1-4051-7024-6.

Camacho, L.M., and Paulus, P.B. (1995). The role of social anxiousness in group brainstorming. Journal of Personality and Social Psychology, 68(6), 1071-1080.

Dix, A., Finlay, J., Abowd, G., and Beale, R. (1998). Human-Computer Interaction, 2nd Edition, Prentice Hall, 463.

East, E.W., Kirby, J. G., and Perez, G. (2004). Improved design review through web collaboration. Journal of Management in Engineering, 20(2), 51-55.

Eastman, C., Teicholz, P., Sacks, R., Liston, K. (2008). BIM Handbook, A Guide to Building Information Modeling, Wiley, ISBN 978-0-470-18528-5.

European Commission Information Society and Media (2006). New Collaborative Working Environments 2020, a report on industry-led FP7 consultations and 3rd report of the Experts Group on Collaboration@work published by the European Commission, Brussels, Belgium.

Fisher, M. and Kam, C. (2002). CIFE Technical Report Number 143: PM4D Final Report. CIFE, Stanford University.

Gallupe, R.B., Dennis, A.R., Cooper, W., Valacich, J.S., Bastianutti, L.M., and Nunamaker, J.F. (1992). Electronic brainstorming and group size. Academy of Management Journal, 35(2), 350-369.

Greif, I. (1988). Remarks in panel discussion on 'CSCW: what does it mean? Proceedings of the Conference on Computer-Supported Cooperative Work, September 16-28, Oregon, ACM, New York.

Grudin, J. (1994). Computer-supported cooperative work: history and focus. IEEE Computer, 27(5), 19-26.

Jessup, L.M., Connolly, T., and Tansik, D.A. (1990). Toward a theory of automated group work: The de-individuating effects of anonymity. Small Group Research, 21(3), 333-348.

Kalay, Y.E. (1998). P3: Computational environment to support design collaboration. Automation in Construction, 8(1), 37-48.

Kelly, J., Male, S. and Graham, D. (2004). Value Management of Construction Projects. Blackwell Science.

Kiviniemi, A. and Fischer, M. (2007). Potential obstacles to use BIM in architectural design, Proceedings of the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 53-65.

Kocaturk, T. (2007). Creative collaboration and distributed cognition in design, Proceedings of the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 66-67.

Kolarevic, B., Schmitt, G., Hirschberg, U., Kurmann, D., and Johnson, B. (2000). An experiment in design collaboration. Automation in Construction, 9(1), 73–81.

Li, H., Huang, T., Kong, C.W., Guo, H.L., Baldwin, A.N., Chan, N., Wong, J. (2008) Integrating design and construction through virtual prototyping, Automation in Construction 17(8), November, 915-922.

Male, S. (2007). The use of 3D-computer visualisation methods in value management briefing and design studies, Presentation at the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November.

Male, S.P., Kelly, J.R., Fernie, S., Gronqvist, M., and Bowles, G. (1998). Value management benchmark: A good practice framework for clients and practitioners, Thomas Telford, London.

Mullen, B., Johnson, C., and Salas, E. (1991). Productivity loss in brainstorming groups: A meta-analytic integration. Basic and Applied Social Psychology, 12(1), 3-23.

Obonyo, E.A. and Anumba, C.J. (2007). Towards a multi-agent approach for knowledge-based virtual construction, Proceedings of the International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 98-111.

Plume, J., and Mitchell, J. (2007). Collaborative design using a shared IFC building model-learning from experience. Automation in Construction, 16(1), 28-36.

Rosenman, M.A., Smith, G., Maher, M.L., Ding, L., Marchant, D. (2007). Multidisciplinary collaborative design in virtual environments, Automation in Construction, 16(1), 37-44.

Riese, M. (2007). Swire Properties' One Island East Tower: a significant BIM success story, International Workshop on Collaborative Human Futures, Cyberport, Hong Kong, November, 124-143.

SAVE International (1998). Value methodology standard, 2nd Revised, Northbrook: SAVE International.

Savioja, L., Mantere, M., Olli, I., Ayravainen, S., Grohn, M., and Iso-Aho, J. (2003). Utilizing virtual environments in construction projects. ITCon, 8, 85-99.

Scaffers, H., Brodt, T., Pallot, M, Wolfgang, P. (2006). The Future Workspace – Perspectives on Mobile and Collaborative Working, a report for the MOSAIC Consortium Project funded by the European Commission as part of the Information Society Theme of the 7th Framework Research Fund.

Shelbourn, M., Bouchlaghem, N.M., Koseoglu, O.O., and Erdogan, B. (2005). Collaborative working and its effect on the AEC organisation. Proceedings of the 2005 ASCE International Conference on Computing in Civil Engineering, Cancun, Mexico, July 12-15.

Teicholz, P. (2004). Labor Productivity Declines in the Construction Industry: Causes and Remedies, AECbytes Viewpoint #4 (April 14, 2004).