ENABLERS FOR CONCURRENT ENGINEERING IN CONSTRUCTION

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ABSTRACT

Concurrent engineering (CE) is implemented through a variety of tools, which facilitate the key CE strategies of multi-disciplinary teamwork, concurrent parallel and integrated processes, and upfront consideration of lifecycle issues. Since this concept was first considered as a viable proposition integrating the construction process, various attempts have been made to develop enabling tools for CE in construction (CEC)

This paper discusses various enablers for CEC. Organization- and technology-based tools are considered, and the extent to which they provide an enabling environment for CEC both with respect to the principles of CE, and the various levels of support required, is also assessed. The analysis revealed that there is broad support (to varying degrees) for CE in construction, but that this is mostly project-centric. There is therefore need for support at the organization level, and also for individuals. Issues relating to the wider implementation of CE identified by the analysis of various enablers suggest that although much progress is being made, there is still more ground to cover. It is also concluded that the role of clients should not be overlooked as they are key to the successful implementation of CE in construction.

KEY WORDS

AEC industry; concurrent engineering; CE enablers; CE tools; Computer integration

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INTRODUCTION

Concurrent engineering (CE), like lean construction and other similar ideas, is one of the concepts from the manufacturing industry which has been advocated as a potentially effective key to the integration of the construction process. The rationale and justification for this has long been established by various researchers (e.g. de la Garza et al. 1994; Evbuomwan and Anumba 1995; and Love and Gunasekeran, 1997) and since then, CE has been (and probably still is) the subject of many research initiatives which primarily focus on the development of appropriate tools and environments for its implementation in the architecture/engineering/construction (AEC) industry. Examples of such initiatives include projects like CLDC (Concurrent Lifecycle Design and Construction), ToCEE (Towards a Concurrent Engineering Environment for Construction), and more recently, the ISTforCE project (Intelligent services and tools for concurrent engineering) (Kamara et al. 2000; Katranuschkov et al. 2002).

The ultimate goal of developing workable (and commercially available) CE tools for the AEC industry is yet to be realized. However, there is now the realization that there are many generic tools, which do not have the CE label, that reflect CE principles (Kamara and Anumba, 2002). This paper therefore describes and assesses some of these tools which provide an enabling environment for CEC with a view to carrying out a reality check on the state of the art in CE implementation efforts. This analysis is also used to identify gaps in CE research efforts and make recommendations for research and development. The term “tool” is used here in a generic sense to include ‘techniques, technologies, frameworks, support structures, etc. that facilitate CE. The principles of CE, which are briefly reviewed, provide the basis for the discussion and assessment of the tools considered in this paper.

CONCURRENT ENGINEERING: PRINCIPLES AND IMPLEMENTATION

Concurrent engineering (CE) is a philosophy which contains (or is implemented by) several methodologies (the ingredients of CE). The earliest definition of CE by Winner et al (1988) refers to “integrated, concurrent design of products and their related processes, including manufacture and support”. This is at the heart of CE, and represents the key principle for CE, with the ultimate goal of customer satisfaction through the reduction of cost and time-to-market, and the improvement of product quality. The attainment of “integrated, concurrent design” requires a variety of enablers which include tools (software applications), techniques, technologies, and support structures. These enablers (e.g. Computer Aided Manufacturing – CAM) can be generic and can be used to support other concepts.

CE embodies two key principles: integration and concurrency. Integration here is in relation to the process and content of information and knowledge, between and within project stages, and of all technologies and tools used in the product development process. Integrated concurrent design also involves upfront requirements analysis by multidisciplinary teams and early consideration of all lifecycle issues affecting a product.

Concurrency is determined by the way tasks are scheduled and the interactions between different actors (people and tools) in the product development process. Table 1 shows a matrix of concurrency which can be used to assess the level of ‘concurrency’ within a project team (Prasad et al. 1993).

Table 1: Matrix of Concurrency (Prasad et al. 1993)

		Work-Group Configurations			
				Simultaneous Users	
No.	**Modes of Interactions**	**Single User**	**Cooperating Users**	**Different Versions**	**Same Version**
1	Access own products' interaction tools or applications (PITA)	Sequential Engineering (SE)	SE	SE	SE
2	Run against their own data	SE	SE	SE	SE/CE
3	Access PITA belonging to other work-groups	SE/CE	CE	CE	CE
4	Access data belonging to other work-groups	CE	CE	CE	CE
5	Access both PITA and data from other work-groups	CE	CE	CE	CE

The rows represent modes of operation and the columns, the possible work-group configurations. A cooperating user is "*a person who completes the work left unfinished by previous users*" (Prasad et al. 1993). Simultaneous users refer to other members of the project team who may access "*the same design, tool or application concurrently, or …different versions of product information tools or applications (PITA) at the same time*" (Prasad et al. 1993). The level of concurrency depends on the type of interactions, and this increases as one moves from top to bottom and from left to right (Table 1). It is observed that some situations are described as both sequential and concurrent: when simultaneous users run their own data, and when a single user accesses the PITA belonging to other work groups (Table 1). The interaction will be sequential if two or more users cannot edit and save changes to a document until another user has finished with it, even though they can be working in parallel. The key features of CE can therefore be summarized to include the following:

- Concurrent and parallel scheduling of all activities and tasks as much as possible.
- Integration of product, process and commercial information over the lifecycle of a project; and integration of lifecycle issues during project definition (design).
- Integration of the supply chain involved in delivering the project through effective collaboration, communication and coordination.
- Integration of all technologies and tools utilized in the project development process (e.g. through interoperability).

CE IMPLEMENTATION ISSUES

The implementation of CE involves the implementation of its key principles using a variety of enablers. The extent to which these principles are implemented determines the level to which the objectives of CE (e.g. shorter lead times) are realized.

CE enablers can be grouped into two broad categories which are interrelated: organizational and technological. Organisational enablers provide the framework for people and machines to work ‘concurrently’. This includes: facilitating the work of multi-disciplinary teams, involving all relevant parties in the product development process, and managerial/technological support for organizational, team and individual levels of working. Table 2 summarizes the kind of support required for CE at the organizational, team and individual levels with respect to distribution, heterogeneity and autonomy.

Technological enablers facilitate concurrent working within organisations. They include all the information and communications technologies (ICTs) and computer-based applications required for integration, concurrent working, communication, and collaboration.

Table 2: Support requirement matrix for CE (Harding and Popplewell, 1996)

	LEVELS		
DIMENSIONS	**Organizational**	**Team**	**Individual**
Distribution	Move information between multiple sites.	Reduce remoteness and promote exchange of information between team members at different physical locations.	Make information available to individuals.
Heterogeneity	Support organizations to achieve different missions.	Support Project Teams to achieve different goals.	Support Individuals to perform different jobs.
Autonomy	Discourage multiple individual stores of information.	Support team members to work as individuals, or as a group, and transitions between these two types of working.	Support individual’s preferred manner of working.

CE IMPLEMENTATION IN THE AEC INDUSTRY

Within the AEC industry, CE implementation needs to account for the unique features of the industry, which is basically organized around projects that are paid for by clients who are technically not part of the industry. AEC projects are also delivered by many firms, unlike the manufacturing industry, where a greater proportion of the skills required may be held within one organisation. Achieving “true concurrency” in AEC (Table 1), for example, might require users from one firm (e.g. structural engineering consultants) to access both PITA (product interaction tools and applications – e.g. CAD workstations) and data from other work groups that might be located other firms.

CE implementation in AEC should therefore be considered at both the project and organisational (i.e. individual consulting/contracting firms) levels. At the organisational level, it is relatively easier to devise strategies that reflect the requirements set out in Tables 1 and 2, which are somehow based on a single-organization model. At the project level, “concurrency” and “integration” should focus only on issues pertaining to the project. The matrix of concurrency in Table 1 is also applicable at this level, but relatively more difficult to implement (see paragraph above); some aspects of Table 2 (e.g. organizational, team and individual support for heterogeneity) may not be applicable since a specific project can be considered as a homogenous entity.

Some of the key challenges for CE in AEC include the linkages between organizational (i.e. firm level) support structures and project level support requirements. Somebody operating at the organizational level may store data on different projects in their PITA; access to information relating to a specific project by somebody outside the organisation therefore becomes problematic. Another challenge relates to the role of clients who dictate the nature and form of the project organization (through procurement and contractual strategies adopted), and in some cases, even the range of technologies that can be used. The fact that the project and organizational levels are influenced by different (and sometimes) opposing forces (i.e. client and industry), poses challenges for the linkages between the two. These conceptual challenges provide the basis against which various enablers for CE in AEC are discussed.

ENABLING TOOLS FOR CONCURRENT ENGINEERING IN CONSTRUCTION

The tools described in this section are discussed under the two broad categories of enablers specified earlier; i.e. organizational and technological.

ORGANIZATIONAL ENABLERS

This category of tools deals with the relationships, roles and liabilities of construction team members. The enablers discussed are: integrated procurement strategies (including partnering), the generic design and construction process protocol (otherwise known as the Process Protocol) and the BEACON (benchmarking and readiness assessment for CE) tool.

Integrated procurement strategies

Integrated procurement strategies refer to those systems that seek to integrate the design and construction process. They include Design and Build, Management Contracting, and in the UK, Private Finance Initiative (PFI) and partnering. Design and Build, for example, provides the opportunity for integrated concurrent design, and upfront consideration of lifecycle issues, through the single-point responsibility of the contractor who is involved at a much earlier stage in the construction process (Anumba and Evbuomwan, 1997). In PFI projects, contractors are involved in financing, designing, constructing and operating the facility, and this can facilitate the incorporation of CE principles.

Partnering is “a management approach used by two or more organizations to achieve specific business objectives by maximizing the effectiveness of each participant’s resources” (ACE, 2000). The approach is based on: shared mutual objectives and compatible benefits; agreed problem resolution methods; shared risk according to who can best manage them; an active search for continuous measurable improvements; and managing the client/supplier relationships proactively. Partnering deals with people, relationships and communication. Team members “choose to live by the spirit, rather than by the letter of the law” (Hellard, 1995). Thus it “attempts to establish working relationships, whereas the contract establishes the legal relationships” (ACA, 2000).

Process Protocol

The Process Protocol (PP) was motivated by the need for project teams to “work to an agreed set of processes and procedures” (Cooper et al. 1998). The PP is designed to facilitate a whole project view, progressive design fixity, and the adoption of a consistent process by all team members (PP, 2002). The PP has nine activity zones and ten process phases (Table 3).

An activity zone is “a structured set of sub-processes involving tasks which guide and support work towards a common objective” (PP, 2002). For example, the activity zone, “development management,” is responsible for creating and maintaining business focus throughout the project; deliverables for this activity include the business case for the project, project brief and concept design plan. Process phases relate to phases in the overall project beginning with “demonstrating the need” (phase 0) up to “operation and maintenance” (phase 9).

Table 3: Overview of the Process Protocol (adapted from PP, 2002)

	Process Phases (0-9)									
Activity Zones	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Development Management	Demonstrating the Need	Conception of Need	Outline Feasibility	Substantive Feasibility/Outline Financial Authority(FA)	Outline Conceptual Design	Full Conceptual Design	Coordinated Design/Procurement/Full FA	Production Information	Construction	Operation and Maintenance
Project Management										
Resource Management										
Design Management										
Production Management										
Facilities Management										
Health/Safety Management										
Process Management										
Change Management										

Benchmark and readiness assessment for CE (BEACON)

BEACON was developed within the overall framework of CLDC. It is an assessment tool for assessing four aspects of an organization’s readiness to implement CE. These are Process, People, Project and Technology (Khalfan et al. 2002). Each quadrant of the BEACON model (Figure 1) contains critical factors to assess the maturity level of an organization. An aggregate score from a set of questions for each aspect (e.g. people) is plotted on the model, beginning from the hub and going outwards. Five levels (Ad-hoc, Repeatable, Characterized, Managed and Optimizing) are used to assess the level of ‘readiness’ in each aspect. “*The Ad-hoc level indicates that an organization is unfamiliar with CE practices or is not ready to adopt CE, whereas the Optimizing level shows that the organization is ready to adopt CE or is already practicing CE within its project delivery process,*” (Khalfan et al. 2002).

TECHNOLOGICAL ENABLERS

This category of tools includes all technologies and software applications that facilitate or support CE. The enablers discussed here are, Groupware, Project Extranets and PlanWeaver.

Groupware

Groupware (Computer Supported Cooperative Work – CSCW) represents a family of products/technologies that are designed to support synchronous and asynchronous group collaboration (Chaffy, 1998). Applications under this category include email, document management and information sharing systems (e.g. intranets), text/video conferencing, and Work Flow Management Systems (WFMS). Tools that support collaborative design (e.g. Virtual Design Studio – VDS (Pan and Kamara, 2003)) and collaborative virtual reality tools (e.g. ActiveWorlds) can also be included under this category. The type and degree of "collaboration" varies depending on the application.

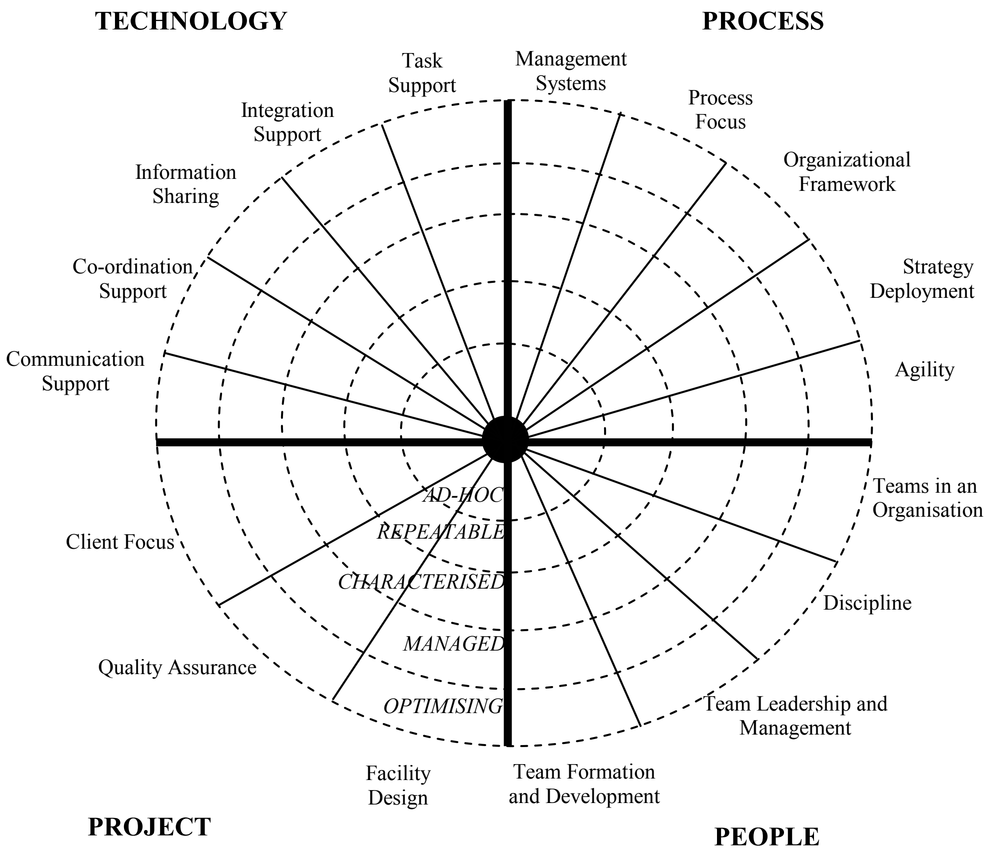

Figure 1: The BEACON Model (Khalfan et al. 2002)

Technologies such as email, which are now common place, provide limited collaborative capabilities. Intranets are becoming more widely used within AEC firms, and these usually combine information sharing and document management capabilities. WFMS do not appear to be extensively used (probably because of their prohibitive cost) in the AEC industry although they are potentially beneficial to the industry; some applications (e.g. Microsoft Exchange, and Project Extranets) do however, have limited workflow capabilities. A VDS can be set up using commonly available software and hardware (e.g. email, electronic meeting systems, and desktop video conferencing) and has been used in some projects which include the collaborative design of an Olympic exhibition pavilion and of a folding screen (Pan and Kamara, 2003). Active Worlds is a Web-based virtual environment which allows users to navigate through a VR model; it also provides chat facilities so that users can ask questions about the model being viewed (see www.activeworlds.com).

It should be pointed out that some groupware applications (e.g. intranets and Microsoft Exchange) are mainly used within organizations, although applications such as Lotus Notes have been use on a major construction project (Gellatly et al. 2000). It should also be noted that technologies that support synchronous collaboration have more scope for CE.

Project Extranets

Project extranets (or project websites) are "dedicated web hosted 'collaboration and information spaces' for the AEC industry that support design and construction teams" (Augenbroe et al. 2001). These sites are hosted by a growing number of 'service providers' (e.g. 4Projects, Bidcom, BIW Technologies and Buzzsaw). Project extranets allow users to share, view and comment on project documents (e.g. drawings, minutes of meetings, specifications, plans, etc.) via a web browser (Kamara and Anumba, 2002). Project extranets utilize client-server internet technology and therefore require access to a web browser. The facilities for collaboration are wide ranging depending on the service provider, and can include any or all of the following (Kamara and Anumba, 2002):

- Sharing, viewing and commenting (redlining) on documents. The installation of propriety software is not normally required to enable users to view and comment on documents. In this regard all (or most) standard file formats are supported. Concurrent viewing of the same document by multiple users is also possible.
- Document management (to varying degrees) including version control, audit trail of documents, tracking and recording of changes, document locking, and search facilities for document/information retrieval.
- Process management through, for example, automatic notification when any document relevant to a user has been changed or added, the ability to send and receive notices, create and respond to RFIs (request for information), and the management of document approvals and change requests.
- A range of communication facilities such as conferencing, threaded discussion forums, and email.

PlanWeaver

PlanWeaver "*is an innovative and unique web-based software application for optimizing business and project processes*," (Adept, 2001). It was developed in response to the need to account for iteration in the design process; its focus is on process improvement through the rationalization of project activities/tasks and their dependencies. PlanWeaver is based on the Analytic Design Planning Technique (ADePT), which uses the Design Structure Matrix (DSM) to rationalize dependencies between tasks and generate an optimum schedule. The stages in the implementation of ADePT/PlanWeaver include: the development of a model of the building design process showing relationships between design activities based on information flows; the analysis and identification of an optimum sequence of activities based on the dependency and availability of design information as defined in the design process model; and linking the optimized dependency matrix of activities to a planning and scheduling package so that the design program can be produced.

ENABLING TOOLS AND CONCURRENT ENGINEERING IN CONSTRUCTION

The challenges for CE implementation in AEC (identified earlier) include support for integrated concurrent design (ICD) at the organization and project levels, and the linkage between the two. The analysis of enablers is with respect to the key features of CE (presented in Table 4), and with respect to the three support levels (presented in Table 5).

Table 4: Enablers and key principles of CE

Enabler	Concurrent and parallel scheduling	Integration of information & lifecycle issues	Integration of supply chain	Integration of technologies and tools
Partnering	No support for *actual* scheduling of activities for concurrency	Provides framework for early integration of lifecycle issues	Supports the integration of supply chains	No direct support, but a collaborative spirit can encourage different parties to use compatible tools
Process Protocol	Consistent processes, progressive design fixity can allow for concurrent scheduling	The whole project view supports the integration of lifecycle information	Some level of supply chain integration through clearly defined processes	No support for integration of tools and technologies
BEACON	No direct support, but it does contribute to achieving all of these by helping an organization to assess its readiness for concurrent scheduling, integration of lifecycle information, etc.			
Groupware (Intranets)	Varying levels of support (e.g. in WFMS) for concurrent scheduling	Some integration of project information. Much support for collaborative design (or working)	Support for integration of people within an organization, but can be extended to include those in other firms	Some integration of technologies (e.g. Intranets and Lotus notes do incorporate various technologies)
Project Extranets	No support for concurrent/parallel scheduling	Some integration of project information in the sense that it is easily accessible	Some support for collaboration through shared space; support for the process of communication; minimal support for coordination (e.g. workflow); no support though for 'true' concurrency (Table 1)	Some integration of technologies (e.g. internet, client-server, encryption, etc.); many file formats are supported indicating a form of open platform for integration different applications
PlanWeaver	Strong support for concurrent scheduling.	Some support for information/lifecycle integration	Little support for supply chain integration	No apparent support for tools/technologies integration

DISCUSSION

The enablers described in this paper represent a small selection of the many tools that reflect CE. However, tools such as partnering, groupware and project extranets represent some of the significant advances in recent years that can positively impact on the implementation of CE in the AEC industry (Kamara and Anumba, 2002). Table 4 shows how the key principles of CE are reflected, to varying levels, in the tools described. For example, only the Process Protocol, some Groupware applications and PlanWeaver seem to support concurrent scheduling of activities. Information and lifecycle integration is supported by all the tools except BEACON, which does not have any direct support, except in helping organizations to better position themselves for CE. Supply chain integration is supported by most, except BEACON and PlanWeaver. Tools/Technologies integration is not supported by the organizational enablers (partnering and PP) and PlanWeaver. The support for CE at the firm and project levels also shows variations in the capability of the enablers described above (Table 5). Most of the support appears to be at the project level, and only BEAON and Groupware provide direct support at the organizational level. Support for organization-project links is also weak, but from the perspective of clients, tools like partnering (within a long-term framework agreement) and the Process Protocol provide a good link between their businesses and the construction projects they commission.

Table 5: Enablers and different support levels for CE in Construction

Enabler	Organization-level Support	Project-level Support	Organization-Project links
Partnering	Some support as confidence at the project level can encourage firms to better align their activities for collaborative working	Strong support: partnering is designed to be create a collaborative spirit within projects	Some support, especially when a partnering contract is within the framework of a long-term agreement with a number of suppliers
Process Protocol	Some support for construction firms through the clarity of processes and deliverables. But strong organization-level support for client organizations	Strong project-level support as the PP is designed to clarify the processes and deliverables within a project	From a client's perspective, there is strong support as the PP links their business goals and projects. Minimal support, through, for construction firms
BEACON	Strong support and this tool is designed for individual organizations	No direct support at this level. Indirect support if individual firms can align themselves to perform at this level	Strong support because the readiness of a firm will ensure that their processes and tools are aligned with projects delivered within a CE context
Groupware (Intranets)	Strong support. Intranets for example, are 'internal' organizational web spaces.	There can be strong support at this level as demonstrated in the case described by Gellatly et al. (2000)	There can be strong organization-project link if the applications used in both are compatible
Project Extranets	No apparent support, especially with third-party (ASP) hosted sites	Strong support as ASP-hosted extranets are very project-centric	No support. Current extranets are designed to separate this link
PlanWeaver	Can provide support in helping individual firms clearly see the dependencies between theirs and others' contribution to a project	Strong support at this level, because the focus of the tool is on projects	Some level of support as described in the first column.

LEVELS OF SUPPORT FOR CE

The brief analysis of various enablers suggests a few things about the current (and future) support for CE that is available. Firstly, there is not, as yet, a single tool that supports every aspect of CE and at every level (i.e. both organization and project levels). However, every principle of CE appears to be supported (to some degree) by at least one tool. This is encouraging, but will potentially lead to 'islands of automation'. It is also contradictory to the principle of CE to "integrate all tools and technologies".

Secondly, the analysis reveals gaps in CE implementation. For example, there appears to be more emphasis on project-level support than on organization-level support and the linkages between the two. The degree of support provided by each tool (e.g. project extranets), with respect to 'true concurrency' (Table 1) is also another area for consideration. Whether this is achievable or indeed desirable within a multi-organization setup like the AEC industry is a matter of debate and further study. Another area that needs attention is support for individuals (Table 2). However, this was addressed in the ISTforCE project which developed a CE Service Platform (CESP) for multi-project participation that focuses on the user (Katranuschkov et al. 2002).

WIDER CE IMPLEMENTATION IN AEC

The relevance of the various enablers discussed in this paper, with respect CE principles and support, has wider implications for CE implementation in the AEC industry. A question that arises is: given all the available tools that reflect CE principles, does the industry now have what it takes to implement CE? My answer to this is both a 'qualified yes' and 'no'. 'Yes', in the sense that CE is meant to be implemented by a variety of tools; using different tools to address different aspects of CE is therefore in this spirit. Even in cases where only some aspect of CE is addressed, this can still be considered as having implemented CE. The cited cases of successful CE implementation in the manufacturing (e.g. in Prasad, 1996) do not suggest that *all* the CE principles were covered – some examples cite only the use of multi-disciplinary teams (already operating in AEC) as their claim to CE fame.

The 'no' response to the question is due a number of factors. Firstly, partial implementation of CE is not enough if the full benefits are to be realized. Secondly, using many disparate tools that don't talk to each other, contradicts CE, as mentioned earlier. Achieving complete tool/technologies integration is obviously a great challenge within a multi-organization context, but if CE if the full benefits of CE are to be realized, this is a goal that must be pursued. However, the focus should not only be on tool/technologies but also between organizational and technological enablers.

CONCLUSIONS

This paper has described some tools that provide support for its implementation in the AEC industry. This was driven by the fact that CE is implemented by a variety of tools which do not necessarily carry the 'CE label'. The discussion was therefore focused on how the tools reflect CE principles and support requirements both at the organization and project levels, and the links between these levels. The analysis revealed that there is broad support for various aspects of CE although the degree to which 'true concurrency' is supported is questionable. The analysis also showed that, while emphasis has been on project-level support, there is need for more organization-based support for CE and support for individuals to work on many projects. The issues on wider CE implementation in the AEC industry discussed suggest that there is still more ground to cover although there is definite progress towards the implementation of CE in the AEC industry. But the role of clients should not be overlooked, because they have a key role in facilitating and paying for a CE-based industry.

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