IMPLEMENTATION OF CONCURRENT ENGINEERING IN CONSTRUCTION – READINESS ASSESSMENT

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ABSTRACT: *There is growing awareness and interest in the adoption of Concurrent Engineering (CE) in the Construction Industry because CE has the potential to make construction projects less fragmented, improve project quality, reduce project duration and reduce total project cost. The urgent need to improve the performance of construction can also be achieved during the design process by concurrently considering key aspects of the construction project's downstream phases. It is evident that by adopting CE, the software and manufacturing industries have significantly improved their business processes.*

While Concurrent engineering (CE) is gaining acceptance, some implementation efforts and plans have not realised their full potential for reducing costs, reducing time, and increasing efficiency, effectiveness and performance for product development efforts in other industries. Therefore, in order to facilitate the adoption of the CE concept in the construction industry, it is also necessary to assess the extent to which firms in the construction industry are ready for the adoption of CE. This can be done by carrying out readiness assessment for any construction organisation before the adoption of CE. Readiness assessment tools and models have been developed and used in other industries such as the manufacturing and software engineering industries.

This paper discusses Concurrent Engineering and its application to construction. It includes a comparative review of existing readiness assessment tools and models that have been successfully used in the manufacturing and IT sectors. It argues that readiness assessment of the construction supply chain is a necessity for the implementation of CE in construction and assesses the applicability of existing tools and models to the construction industry. A new readiness assessment model for the construction industry called "CERAMConstruct" is then presented. In the end, a summary of whole paper is presented and aspects of further work to be done are also outlined.

KEYWORDS: Concurrent Engineering (CE), CE in Construction, CE Readiness Assessment, CE Readiness Assessment Tools and Models.

1. INTRODUCTION

There is growing awareness of the need for changes within the construction industry in its current practices and processes of project development which include design, procurement, construction, project delivery etc. This is mainly caused the dramatically decreasing construction costs through standardisation of construction processes (CIRIA Report, 1999); the increasing demand and sophistication of clients (Wognum et al., 1996); the rising requirements for project functionality through growing competition; the rapid developments in communication and information technologies; and the recommendations in UK Government-initiated reports such as the Latham Report (1994) and the Egan Report (1998). Many construction companies are responding to this increasing importance of project development processes by incorporating Concurrent Engineering practices to improve their project development capability (de Graaf & Sol, 1994).

Concurrent Engineering (CE), sometimes called simultaneous engineering or parallel engineering, has been defined in several ways by different authors. The most popular one is that by Winner et al. (1988), who state that concurrent engineering "…is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements."

In the context of the construction industry, Evbuomwan & Anumba (1998) define Concurrent Engineering as an "…attempt to optimise the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction and erection activities and by maximising concurrency and collaboration in working practices." This is in sharp contrast with the traditional approach to construction project delivery.

While Concurrent engineering (CE) is gaining acceptance, some implementation efforts have not realised their full potential for reducing costs and reducing time for project development efforts. This is due in part to weak planning to support the CE implementation (Componation & Byrd, 1996). One method that has been used successfully to improve planning is to conduct an organisation readiness assessment prior to the introduction of CE

Therefore, this paper reviews and compares the existing Concurrent Engineering (CE) Readiness Assessment Tools and Models, checks their appropriateness for the Construction Industry in the light of current practices within the industry and describes a new Readiness Assessment Model for the construction industry.

2. CE READINESS ASSESSMENT

2.1. Introduction

As mentioned in the previous section that one approach which has been successfully used to improve CE implementation planning is to conduct readiness assessment of an organisation prior to the introduction of CE. This will help to investigate the extent to which the organisation is ready to adopt Concurrent Engineering (Componation & Byrd, 1996), and to identify the critical risks involved in its implementation within the company and its supply chain. CE Readiness Assessment has been successfully used for the planning of CE implementation in several industry sectors, notably manufacturing and software engineering, as described in the next section.

2.2. Readiness Assessment Tools and Models

2.2.1. An Overview of Tools & Models

There are several tools and models, which are being used for readiness assessment of organisations for concurrent engineering. A brief description and comparison of the models and tools (see Table 1) are presented below:

a) RACE (Readiness Assessment for Concurrent Engineering)

This tool was developed at West Virginia University (United States) in the early 90's and is widely used in the software engineering, automotive and electronic industries. It could be modified for use in the construction and other industries. The RACE-model is conceptualised in terms of two major components: Process and Technology (CERC Report, 1993; Wognum et al., 1996). The Process component is subdivided into ten elements and the Technology component into six as shown in Table 1.

b) PMO (The Process Model of Organisation)

This model was developed to assess and analyse the processes and technology of an organisation. The process model of organisation (PMO) is a model, which can basically be used for analysing and designing an organisation, its processes, and technology in the context of the market in which that organisation operates. The model is used to detect bottlenecks that prevent the organisation to achieve its objectives (Wognum et al., 1996).

c) PMO-RACE (A Combination of PMO & RACE)

PMO-RACE is the combination of two models (PMO and RACE) which was developed by the researchers at University of Twente and Eindhoven University of Technology (Netherlands) in the mid 90's. Since the Process Model of Organisations (PMO) can support the identification of key problem areas and the definition of business drivers while the RACE-method is good at determining the performance level of the product development process, it was suggested that both methods could be combined to support improvement cycles. The combination would deliver 'the best of both worlds' (de Graaf & Sol., 1994).

d) PRODEVO (A Swedish Model Based on RACE)

PRODEVO was developed at SISU (Swedish Institute for Systems Development) and this development was parallel to the development of PMO-RACE tool. Some of the dimensions and also a couple of the questions are assimilated in the presented tool from RACE model, and to indicate a relation the working name, "Extended RACE", was adopted earlier (Bergman & Ohlund, 1995).

e) CMM (Capability Maturity Model)

CMM was basically developed for software development and evaluation and was developed by the Software Engineering Institute at Carnegie Mellon University in order to manage the development of software for the US government, particularly that which was to be used by the Department of Defence in late 80's (Aouad et al., 1998). This model can be used as readiness assessment model and, in fact, the RACE model was developed based on ideas from CMM.

f) SPICE (Standardised Process Improvement for Construction Enterprises)

This tool was developed at the University of Salford, United Kingdom, and is in the form of a questionnaire, which is designed to evaluate the key construction processes within a construction organisation (SPICE Questionnaire*,* 1998). SPICE is basically intended for evaluating the maturity of the processes of construction organisations. It is based on CMM and is presently a research prototype (Finnemore & Sarshar, 2000).

g) Project Management Process Maturity $(PM)^2$ Model

This 5-Level $(PM)^2$ Model was developed at University of California, Berkeley in late nineties. The primary purpose of the 5-Level $(PM)^2$ Model is to use as a reference point or a yardstick for an organisation applying PM practices and processes. This 5-Level $(PM)^2$ Model further suggest an organisation's application expertise and the organisation's use of technology, or it might produce recommendations on how to hire, motivate, and retain competent people (Kwak & Ibbs, 1997).

h) SIMPLOFI Positioning Tool

The tool was designed and developed by the Department of Manufacturing Engineering at Loughborough University. It formed part of the output of the SIMPLOFI (***Sim***ultaneous Engineering through ***P***eop***l***e, ***O***rganisation and ***F***unctional ***I***ntegration) project in the mid-nineties. The tool focuses on the introduction of one specific product in an organisation. This tool assists those people who are responsible for product introduction within an organisation in answering the question: "I know what product I want to introduce – How do I organise the introduction of this product to achieve this most effectively?" (Brookes et al., 2000).

2.2.2. Framework for Comparison

The framework for comparison discusses the characteristics of the available tools and models under a number of generic criteria, which include:

- Aspects covered: which discusses the main issues addressed in each tool;
- The status of the tool: which shows the current standing of the model/tool in terms of whether it is a research prototype, commercial tool or currently under development etc.
- Survey method: which identifies how the data collection is carried out – that is either by questionnaires, interviews or both;
- Software availability: this identifies those tools and models which are accompanied by a software that can be used during the readiness assessment;
- Ease of use: an indication of the user-friendliness of the tools/models;
- The Usage of Tools for Readiness Assessment for CE: this identifies the tools and models which can be used for CE readiness assessment; and
- Applicability to the construction industry: since the basic purpose of this comparison is to identify the most suitable tool/model for the construction industry, this criterion assesses the potential use of the models and tools in the construction industry as a CE readiness assessment tool.

2.2.3. Findings

Table 1 gives an overview and comparison of available tools and models, which are being used to facilitate CE within an organisation. The comparison is based on the framework, which has already been discussed in the previous section.

From the comparative analysis (Table 1), it could be concluded that most of the tools and models discuss improvements in the product development process, and the use of technology to facilitate the development process. Some of the tools and models also cover the organisational environment to support the development process. The status of the tools and models shows that most of the tools and models are under development but some of them are being used on a commercial basis. With regard to software availability, there are only a few tools and models which are accompanied by their own software. Most of the tools and models are easy to use and user-friendly. Most of the tools and models reviewed were developed to assess the product development process within an organisation but can be used as a CE readiness assessment tool after appropriate modification. However, some of the tools and models were basically designed for CE readiness assessment. An assessment of the use of these tools and models within the construction industry shows that none of the tools and models is ideally suitable for use in construction as a readiness assessment tool for CE (Khalfan & Anumba, 2000).

3. CE READINESS ASSESSMENT OF THE CONSTRUCTION SUPPLY CHAIN (CSC)

3.1. The Need

As discussed in Section 2, CE Readiness Assessment is used to improve CE implementation. It is conducted before the introduction of CE within an organisation, and investigates the extent to which the organisation is ready to adopt CE. While this has been carried out in other industry sectors, it is unusual for such assessments to be undertaken in construction supply chains. Furthermore, Muya et al. (1999) show that current industry practices do not support integration of the whole supply chain during the construction process. It is therefore imperative that, for CE implementation in the construction industry to deliver the expected benefits, readiness assessment of the construction supply chain should be undertaken. This will ensure that all sectors of the chain have reached an acceptable level of maturity with respect to the critical success factors for CE implementation, and may indicate the likelihood of the following benefits:

- Better and more effective CE implementation within CSC;
- Enabling the CSC to evaluate and benchmark its project delivery processes;
- Development of more appropriate tools for CE implementation within the CSC;
- Enabling the CSC to identify areas which require improvements or changes; and
- Enabling the CSC to realise the need for CE implementation in order to bring about improvements in the whole project delivery process.

3.2. Which Assessment Model?

After analysing the comparison matrix (see Table 1), it could be said that RACE would be the most appropriate for use as the Readiness Assessment Tool for Concurrent Engineering in the construction industry because of the following reasons:

- Aspects covered in RACE model such as customer focus, team formation, management systems, communication & integration systems, etc., can be used readily for CE readiness assessment in the construction industry, after some modification, due to the similar structure and requirements of the construction industry;
- Commercial usage of RACE model makes it more reliable;
- RACE model questionnaire addresses and assesses the critical business drivers in the construction industry; and
- Since RACE is basically a CE readiness assessment model, therefore, it is more appropriate than other tools and models, which were developed to assess the project/product development process within an organisation.

Table 1: Comparison of CE Readiness Assessment & Implementation Tools & Models (Khalfan & Anumba, 2000)

Tools/Models→ Criteria↓	**RACE**	**PMO**	**PMO-RACE**	**PRODEVO**	**CMM**	**SPICE**	**$(PM)^2$**	**SIMPLOFI**
Aspects Covered	**Process** • Customer focus. • Product Assurance. • Leadership. • Team formation. • Strategy deployment. • Agility. • Teams within the Organisation • Process focus. • Management system. • Discipline. **Technology** • Project Architecture. • Application tools • Communication. • Co-ordination. • Information sharing. • Integration.	**Organisational Environment** • Task environment. • General environment. **Processes** • Primary processes. • Control processes: *Strategic level, Adaptive level, & Operational level* • Support processes.	Aspects covered are the same as PMO & RACE because this is the combination of both of these tools.	• Customer & user focus • Process focus • Team & project focus • Life-cycle perspective • Communi-cation	**Process** • Pre-project Phase • Pre-construction Phase • Construction Phase • Post-construction Phase **Information Technology** • Simulation • Integration • Intelligence • Communica-tions • Visualisation • IT support	• Brief Management. • Project Planning. • Project Tracking & Monitoring. • Contract Management. • Quality Assurance. • Project Change Management. • Risk Management. • Organisation Process Focus. • Organisation Process Definition. • Training Programme. • Inter-disciplinary Co-ordination. • Peer Review. • Technology Management.	• Planning to execute a project • Definition of project activities • Cost estimates for the project • Project Management (PM) process • PM-related data collection and analysis • Utilisation of PM tools and techniques • Working as a team • Senior management support	• The structure of teams • Control mechanisms (whether control mechanisms should reside with functions or projects) • The degree to which the process should be parallelised • How specialised people operating the process should be • The degree of automation in the tools used.
Status of Tool/Method	Commercial	Development Ongoing	Development Ongoing	Development Ongoing	Commercial	Research Prototype	Development Ongoing	Commercial

Survey Method	Questionnaire & Interview.	Interviews, Description of past and current projects, formal procedures and quality hand book	Questionnaire & Interview.	Questionnaire.	Questionnaire & Interview.	Questionnaire.	Questionnaire.	Questionnaire.
Software Availability	Yes, also uses other software (e.g. SPSS).	Can use any modelling software.	Yes	None.	Yes, but also use other software e.g. SPSS.	None.	None.	Yes.
Ease of Use	Yes, but technological aspect is complicated to answer and is only for specialists.	Yes, but seemed to be incomplete, that's why merged with RACE later on.	Yes, and it seems to be completed after the combination of PMO & RACE.	Yes	Yes	Yes, MCQs are developed with additional space for comments.	Yes.	Yes, user-friendly software.
Can be used for Concurrent Engineering Readiness Assessment?	Yes, basically made for this purpose.	Basically used for analysing & designing organisations.	Yes, mainly for readiness assessment but also used for CE implementation process.	Basically developed for assessing concurrent engineering (CE) process.	Yes, but basically used for CE Implementation process.	Basically used for Process Improvement.	Basically used as a yardstick for an organisation applying PM practices and processes.	Basically used to assist those, who are responsible for product introduction within an organisation.
Appropriateness for use in Construction	Yes, but requires some modifications.	Yes, but basically used for analysing and designing an organisation, its process and technology.	Yes, but RACE model requires modification before applying to construction.	Yes, but it requires changes to address construction specifically.	Yes, but basically developed for software industry, therefore it requires changes before applying to construction.	Yes, but this tool is basically made for process improvement within construction projects.	Yes, but this tool is basically developed to determine and to position an organisation's relative PM level with other organisations.	Yes, but this tool focuses on the introduction of one specific product in an organisation. Therefore, in any construction organisation, it can be used for a specific project and it would give the position of the project and not the position of the organisation.

However, the RACE model requires adaptation and modification for this purpose because, basically, this tool was developed for readiness assessment for concurrent engineering in other industries such as manufacturing and software engineering industry. Thus, it needs to be tailored to the requirements of the construction industry and the people working within the industry. The following are some of the reasons which indicate that RACE in its current form is not suitable for the construction domain and requires modification for use in assessing the construction industry:

- RACE is basically designed for assessing the readiness of other industries such as software, automotive, manufacturing, and electronic industries, all of which have different characteristics to construction;
- Aspects covered focus on the processes in the above mentioned industries and require changes to assess the construction process;
- The structure of teams within above mentioned industries are different from typical construction project teams;
- The level of technology usage in the afore-mentioned industries is different from that in the construction industry;
- The products of the other industry sectors satisfy a large number of customers whereas a construction project is one-off in nature, typically fulfilling the needs of a particular client or organisation;
- The level of integration, communication, co-ordination, and information sharing are different between construction and the above-mentioned industries; and
- Managing a manufacturing product and a construction project require different levels of management skills.

4. DEVELOPMENT OF A CE READINESS ASSESSMENT MODEL FOR CONSTRUCTION INDUSTRY

4.1. Introduction

A CE readiness assessment model is being developed for assessing the construction industry. The proposed model, named ‘Concurrent Engineering Readiness Assessment Model for Construction’ (CERAMConstruct Model), is shown in Figure 1. A questionnaire has been developed for the model, which covers all the elements shown in the new model. The proposed model has similarities with the RACE Model in terms of the key assessment elements (i.e. most of them cover the same issues), questionnaire criteria, and diagrammatic representation (spider or radar diagram). However, it differs from the RACE model in that it focuses specifically on construction processes.

4.2. Key Criteria for the Model

Key criteria of the new proposed model for the construction industry are the same as for the RACE model. Since the purpose of the model is to assess the readiness of a construction organisation for the adoption of CE practices, it must include both the process aspect of the construction industry as well as the technology aspect, which facilitates the construction processes. The process aspect includes the client focus regarding the project, improvement in the construction process itself, formation and development of teams for carrying out project tasks, improving the management systems of the organisation, maintaining the project and process standards, bringing agility into the construction process, and employing and exploiting project strategy. The technology aspect includes the services related to communication, co-ordination, information sharing and integration (Khalfan & Anumba, 2000).

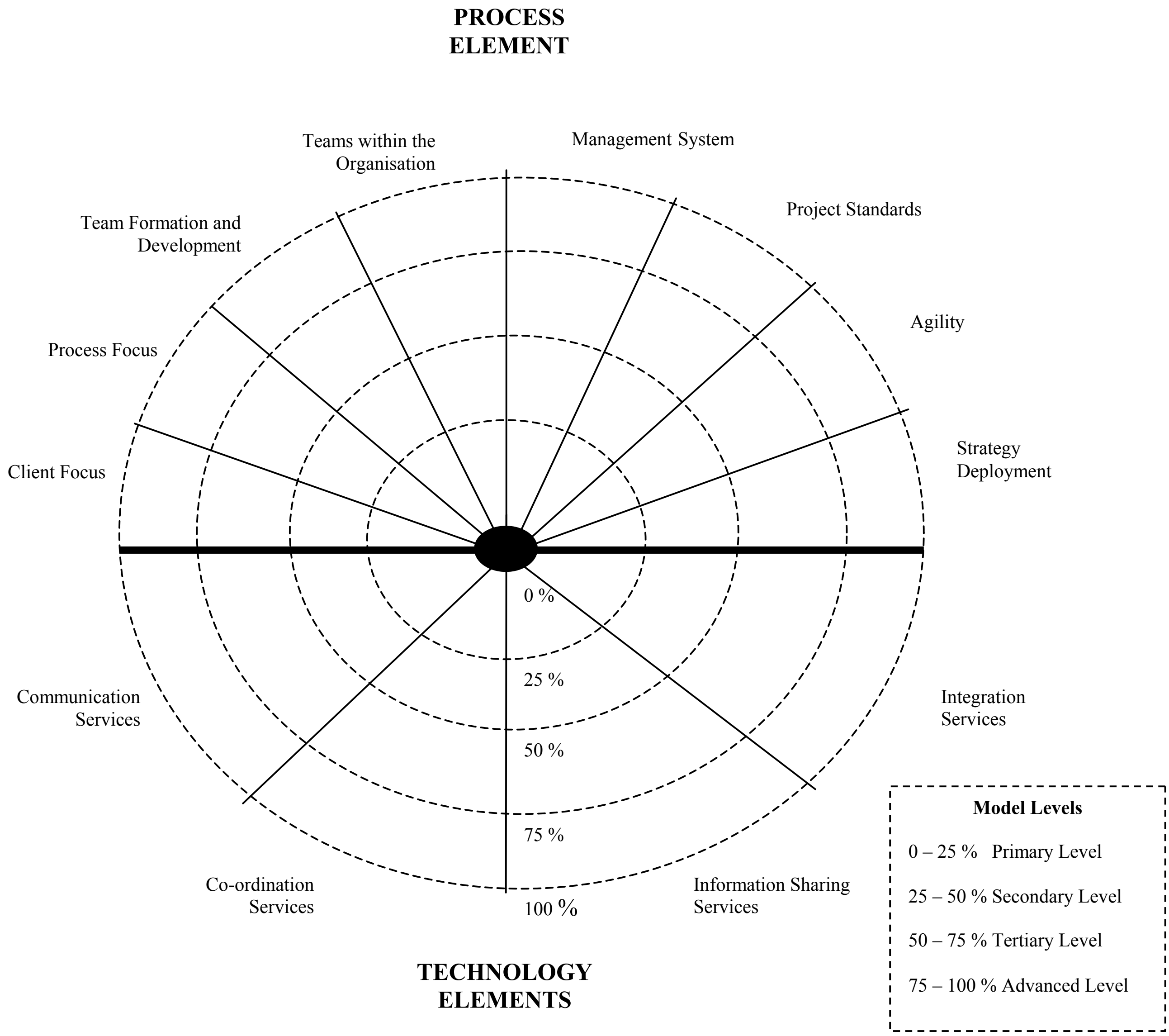

Figure 1: CERAMConstruct Model

4.3. The CERAMConstruct Model

The CERAMConstruct Model is divided into two sections (see Figure 1). The upper half contains eight process elements used to assess the process maturity level of a construction organisation. The lower half contains four technology elements used to characterise the introduction and utilisation of advanced tools and technology within the organisation. For both process and technology elements, four levels have been defined, which indicate the quality of the process and technology employed within the organisation. These four levels are Primary Level, Secondary Level, Tertiary Level, and Advanced Level, as shown in Figure 1. The Primary Level indicates that an organisation does not have any idea about CE practices or is not ready to adopt CE whereas Advanced Level shows that the organisation is ready to adopt CE or is already practising CE within its project delivery process.

A model-based questionnaire (called the CERAMConstruct Questionnaire) has been developed for use in assessing construction organisations. The elements covered in this model are assessed using this questionnaire. The assessment scale has five possible options: “Always”, “Most of the Time”, “Sometimes”, “Rarely”, and “Never”. The CERAMConstruct Questionnaire can be used for assessing CE readiness of:

a) A static construction organisation, for example an architectural or construction organisation etc., having their own organisational structure and having different teams for different on-going projects, and
b) A virtual construction organisation, which consists of various members from different construction organisations, forming a Project Development Team (PDT) and working on a single project. Figure 2 illustrates the PDT and its sub-teams which are responsible for supervising the whole project development process from inception until hand-over (Khalfan, 2000).

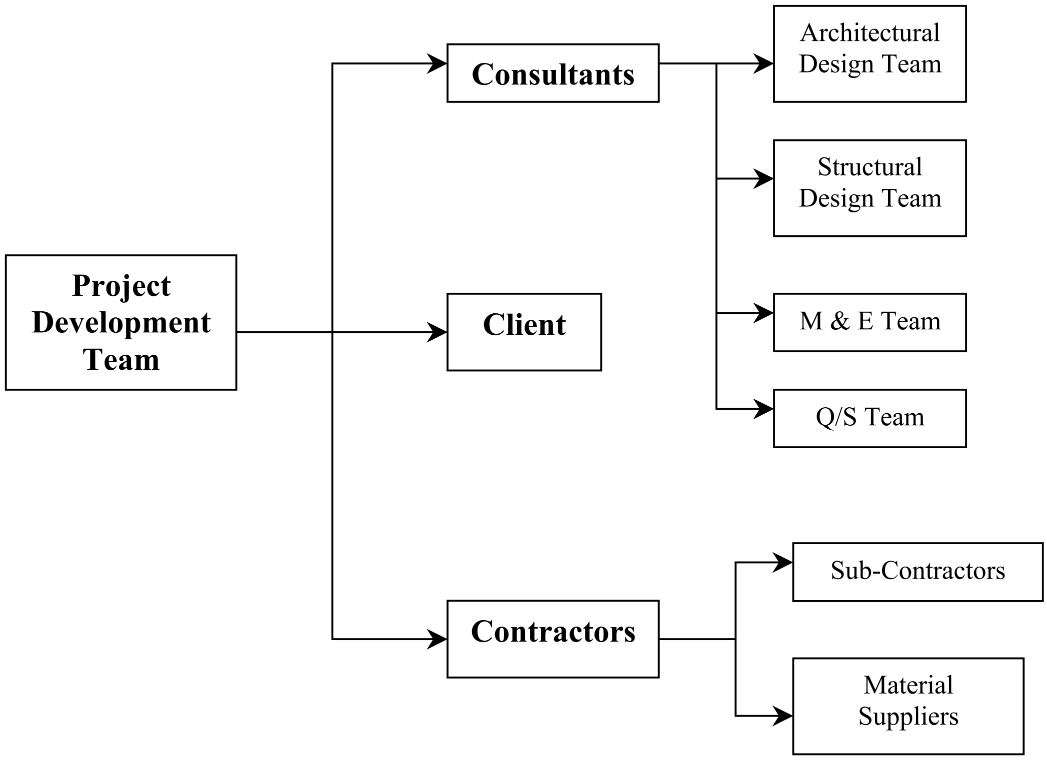

Figure 2: Typical Team Structure within a Virtual Construction Organisation

5. FURTHER WORK

For the construction industry to contribute towards client satisfaction by improving quality, adding greater value, reducing cost, and reducing construction schedules, much is still needed to be done in improving relationships within the overall construction supply chain. Therefore, improvements and further development of the new model for assessing the CE readiness of the construction supply chain, is being carried out. Further work is focusing on the following:

- Refinement of the CE Readiness Assessment Model for Construction;
- Development of a CE Readiness Assessment Software;
- Detailed survey and assessment of key sectors of the construction supply chain using the prototype software; and
- Formulation of CE implementation strategies for the construction industry.

6. SUMMARY & CONCLUSIONS

This paper has discussed the need for readiness assessment of the construction supply chain for the implementation of concurrent engineering (CE). In the early part of the paper, CE and its application to the construction, and readiness assessment of CE were introduced. Then a comparative review of existing tools and models for CE readiness assessment was presented and the limitations in their use for assessing the construction industry are also highlighted. The need and potential benefits of CE readiness assessment of the construction industry were then examined. The outline features of a new CE readiness assessment model for the construction was presented and further work outlined.

The following conclusions can be drawn from the work presented in this paper:

- CE is relatively new approach, which can make construction project teams less fragmented, improve project quality, reduce project time-scales, and reduce total project cost;
- There is need for improvements to the way the construction supply chain (CSC) delivers projects, so as to achieve client satisfaction and overall improvements in efficiency, effectiveness and profitability;
- CE has a potential to improve the construction industry in the above mentioned area;
- It is necessary to carry out CE readiness assessment of Construction industry before CE implementation so as to ensure that maximum benefit is achieved;
- There is also a need to develop an appropriate CE readiness assessment tool or model for the CSC, as existing models are not appropriate in their present form.

Clearly, the construction industry stands to reap significant benefits from the adoption of CE. The conduct of a readiness assessment is of the essence in ensuring that the right approaches are adopted. The work presented in this paper is contributing in this regard and will, in future, provide detailed guidelines for effective CE implementation in the construction industry.

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