# MANAGING DISTRIBUTED DESIGN TEAMS AND PROCESSES: A CROSS-SECTOR STUDY OF CONSTRUCTION AND AEROSPACE

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This paper explores cross-sector features for ways to improve the working environment of designers who operate in distributed teams. The influence of ICT tools in design is fostering a shift in the way designers work now and into the future. Whilst their current skills would still be relevant in the emerging work environment, additional skills and know-how become apparent. The paper has explored how technology is influencing the design environment of distributed teams including the use of groupware and extranet-based collaborative workspaces to aid designers operate in multi-participant, distributed projects. It has proposed the use of a prioritisation matrix as an analytical framework for generating commonality factors from two sectors to serve as support information for productivity improvement of designers who operate in distributed environments.

Keywords: design, construction, aerospace, collaboration, prioritisation matrix.

## INTRODUCTION

This paper presents a discussion of initial work that forms part of a larger multi-disciplinary research project focusing on the future of design processes and practices in general and the convergence of these practices across different specialities of design. The basic motivation of the work derives from the enabling environment created by advancements in the deployment of ICT (Edum-Fotwe *et al.*, 1999). This has made considerable in-roads into the actual physical generation of design solutions with a conterminous impact on the work environment and new intra-organisation relationships that designers have to cope with. How designers work in these emerging environments forms the nexus of this paper

The subsequent sections of this paper explore the emerging trends in the work environment of designers and engineers and the context of design environments in two sectors that form part of the wider project study. It also outlines and examines a simplified version of a framework for identifying dominant features and commonalities that will influence the nature of collaborative work for designers in the two sectors.

## DESIGN ORGANISATION WORK TRENDS

The intensifying trend in global economic competition has compelled many organisations to pursue a path of exploring all possible options for achieving greater

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effectiveness and efficiency in their working environment on a continuous basis (Drucker, 1994). The availability of current technology and structured administrative systems for improving productivity, which is obtainable by all organisations, therefore shifts the emphasis for the required competitive improvement to the untapped potential of the workforce as the primary distinguishing factor in organisational performance (Cooper *et al.*, 1998; Kagioglou *et al.*, 1998). Such a shift gives rise to the following *three* main imperatives for present and future design organisations and the environments in which designers work: namely, collaborative effort driven by high-intensity concurrency, growing emphasis on human skills and competencies, and enhanced corporate role for frontline designers. The relevance of each of the three imperatives for designers is briefly discussed below.

**Growing collaboration**

Recent workplace innovations of a general nature such as employee involvement and empowerment, has resulted in greater recognition that workers at all levels of the organisation are a significant source of creative thinking (Kotter and Heskett, 1992). Consequently, the traditional division of work between *thinking* and *doing* is gradually melding, requiring all workers to become part of an organisation-wide collaboration process (Leimeister *et al.*, 2001). This is because the development of design solutions for projects and products often involve complex processes, activities and resource inputs that demand participatory effort from several stakeholders. This is particularly the case for construction and the aerospace sectors.

The presence of project-oriented consortia and short-term alliances in most design communities often means projects must be carried out using a distributed work arrangement because of stakeholders who may be dispersed in different geographical locations.

On another level, this collaboration will have to be fostered between different organisations that contribute to distributed-teams for the design or manufacture of a specific product (Thompson, 1967). This is largely due to the range of specialisation that is required for the design of products in aerospace and construction sectors, and for which it is rather uneconomic for any one company to retain the technical skills and organisational capabilities.

On a third level, similar collaborative effort can be identified within production-chains, value-chains, supply-chains and *design-chains* (Austin *et al.*, 2001). Construction and engineering organisations are increasingly looking to their collaboration efforts to make design engineering more a part of the supply chain by doing away with design as a business-process silo and getting the company's engineers and its suppliers working together. For example many global manufacturers are trying to create an approach to design and manufacturing that can be described in terms of *design anywhere, build anywhere* in order to bring designers closer to the end-users of their products.

These collaborative efforts are often represented within organisations in the form of group-work or teamwork. There is ample evidence that the use of team-based problem solving, innovation, and product development is on the ascendancy and could accelerate to become the standard operating processes in aerospace, manufacturing and construction sectors (Morris *et al.*, 2000). Some of the evidences for this changing trend towards team-based approaches in organising work include the following:

Growing use of employee teams

Re-design of workplace systems and physical space to enhance collaboration

An increase in team-based education at primary, secondary and tertiary levels

Evolution of team-centered software (e.g. Lotus Notes, Intranets, ERP)

A re-definition of production away from functional to process models

A growing awareness of deutero-knowledge as a key organisational asset.

**Technical versus human skills and competencies**
Traditionally, designers are required to display a demonstrable level of high technical, some administrative, and decision-making abilities in the workplace. This orientation derives from the conventional thought that design engineers will be managed by a design manager who will provide the organisational leadership and where necessary, to control the behaviour of employees in design organisations and environments.

With increased competition many design organisations have had to rethink design management/design worker configurations significantly, as this paradigm of work is being challenged (Galbraith and Lawler, 1993). The control mentality is being replaced by a commitment mentality as workers are being asked to take on more responsibility and accountability. Design engineers therefore, have to understand human behaviour and potential, as well as how to engender co-operation and collaboration, and stimulate creativity and innovation. The ability of designers to cope with this added new roles will driven by the acquisition of requisite social and human skills and competencies to combine with their technical demands (Edum-Fotwe *et al.*, 2000).

**Enhanced frontline designer**
Within the design environment no other role will be as affected by competition as that of the frontline design worker. As design management ranks thin out, more of the tasks formerly performed by these design managers will move to the front line design worker. These design workers, without day-to-day guidance, will depend more on themselves for direction and resources. They will also need multiple skills to accommodate shifting priorities and needs within the organisation (Thorpe *et al.*, 1998). They will operate more as independent contractors within a team context, moving from team to team as the need arises. This will place a challenge on the design worker to take full responsibility for rapid development and renewal of their skills. Therefore, the design worker of the future will need to understand a full range of technical and administrative skills such as budgeting, planning and scheduling, quality control, performance measurement, vendor and customer interaction, hiring, purchasing, process improvement, problem solving, procedure development, and more. This will go hand in hand with the required authority to ensure that design processes proceed with the minimum redundant time and effort.

## DESIGN COLLABORATION AND TECHNOLOGY

Many design organisations are currently attempting to come to terms with the demands of collaboration in the form of distributed work environments by using group-enabled software products and collaborative strategies. Since the 1990s, proprietary groupware packages have found increasing usage by large organisations to aid communication and collaboration when operating in a distributed work environment. At the close of the 20th century, non-corporate network-based collaboration models, such as intranets and extranets, started gaining popularity as alternatives to other proprietary systems. These internet-based alternatives bypass the need for corporate local area networks (LANs) or wide area networks (WANs) by using the Internet as their network infrastructure to connect remotely located, collaborating group members. Equally, the transformation underway in the fields of data sharing and transmission, information processing, and telecommunication technology is opening up new possibilities in the way designers work. The dynamic nature of design processes in construction and aerospace, the interdependence of various participating entities, and the need for teamwork, flexibility, and a high degree of coordination suggest that IT systems should be profitably employed for effective design management in these sectors.

The distinctive features of construction and aerospace projects make the task of design management particularly appropriate for applications of IT tools. Some of these features and the roles IT can play regarding them are discussed below.

The work atmosphere under which design projects are managed continually changes, requiring exchange of information in different forms. For this reason the design environment needs to be flexible to facilitate communication. IT systems can promote rapid communication, not only through voice media, but also by facilitating transmission of text and graphic information on a real-time basis.

The design process is based on complex relationships between a variety of individuals, entities, and groups. Processes are often not well defined. The interdependence of process segments can be critical to the success of the whole development of a design solution. Interaction between design team members can be helpful in providing effective leadership and in motivating team members. IT can reduce the need for bureaucracy and hierarchy of interaction and can enhance integration of organisational activities from different corporate establishments.

In theory, the opportunities provided by such technology for collaborative work arrangements should provide a number of advantages, including a reduction in duplication of effort and wastage of resources (Fry and Slocum, 1984). In practice, however, these advantages are often not realised due to limitations in current technology. For example Finley and Coleman (1999) provide analysis of a multi-participant, distributed project and identified a number of problems that are likely to be magnified in distributed environments. These include problems in communication, information movement, collaboration, project co-ordination, and management. The continued use of existing technologies will however, ensure their maturation and so influence the way designers undertake their work. Reaching a critical mass of adoption is especially important for design-collaboration software for one major reason: If your partners don't use it, it's a lot less useful to you.

## COMMONALITY ISSUES

The explosion of knowledge and information over the past three decades has helped to open up traditional disciplines, which have in the past been limited by the pigeon-hole of defined discipline boundaries. Attendant to this opening up of traditional disciplines has been the recognition of significant overlap in the way work patterns and practices in different professional areas and business sectors reflect considerable commonality in work environments. The establishment of commonalities in work and process practices and activities has fostered opportunities for bringing about considerable improvement in both engineering and commercial operations. For example, within the UK, these opportunities have included the consideration of *Construction as a Manufacturing Process* (CMP), under the public funded programme of *Innovative Manufacturing Initiative* (IMI). This orientation for construction has resulted in projects such as the process protocol (PP and PP2), and other schemes that have attempted to re-configure construction from a process viewpoint, as against the well-known and practiced functional approach. The limitations of the functional approach for organising production activities in construction industry has been given much consideration elsewhere and will therefore not be repeated in this paper (Galbraith and Lawler, 1993). The process approach on the other hand offers potential opportunities for achieving a well-integrated production system for construction. A significant number of research projects have focused on the production side of the construction industry and exposed aspects where productivity improvements can be gained from the process approach.

While the design function in most engineering or technology based disciplines is well-appreciated by the designers who work in that domain, the benefits of developing crossover perspectives for designers from different backgrounds has often been hampered by a number of factors. These include:

1 A commonly accepted notion that detailed activities of the design process cannot be modelled in the same way as production activities. As such, the design process is often appreciated only at the broader and more generic level.

2 Design concepts and solutions are often considered to be predominantly esoteric in nature. As such a rational approach is deemed to serve as a limitation on innovation and potential solution options (Chang and Ibbs, 1998, 1999).

3 The notion that there are no common grounds in the work of designers from different disciplines as the products they generate are entirely different. Such an argument may be valid from the standpoint of a technical solution, but not the processes involved in the development of design solutions. It is essential to bear in mind that similar arguments had been addressed at the production side.

By focusing on the process and not the product it is possible for areas of commonality to be established for design activities in different sectors. The next section briefly outlines the main phases of such a general process view for design that could form the basis of establishing commonality analysis. It has to be mentioned that other proprietary process models that reflect specific sectors exist including the PP2, which could form the basis of any such analysis. Further information on the scope and phases of the PP2 can be obtained from www.pp2.dct.salford.ac.uk.

**Design process introspection**

Design is not a single action, but is a translation of ideas into reality through a set of process activities (Cross, 1989). The order in which these process activities are undertaken, and the interaction between the various process activities, can affect rate of progress in arriving at the design solution and also, more importantly, the quality of the eventual completed product. Some of the main process activities in design include:

1 Requirements
2 Analysis
3 Concept
4 High Level Design
5 Design Embodiment

6 Prototype
7 Testing
8 Production
9 Maintenance

The traditional view of the design process is as a sequence of processes, where one process must be completed before the next one can be started. These design processes can apply not only to product design, but also to other domains such as software engineering. Within construction, there exists little scope for the prototyping and testing phases although it is known to exist on some major schemes for critical units (for example mock-ups on how a new orientation for integrated bed units within a hospital would fit into the delivery of in-patient services). The main characteristic of the design process is the large number of feedbacks or iterations. Such feedbacks and iterations emphasise considerable interaction and collaboration between individual designers and other participants involved in developing the design solution.

**Productivity in design work**

It is often thought that knowledge work as reflected by design is not manageable. The work of design engineers, similar to other knowledge work, does not require definite work forms, such as repetitive motions, that are usual with blue-collar work. Design engineers usually do not directly produce physical products and are away from the final outputs. It is therefore considered difficult to measure their performance and estimate their contributions. According to Drucker (1991) the single greatest challenge facing managers in the twenty-first century is to raise the productivity of knowledge and service workers. In construction, and especially for design projects, engineers have a high level of influence on project performance, but there is only limited research targeting their productivity. For example Anderson and Tucker (1994) and later Thomas *et al.* (1999), established criteria to evaluate design effectiveness and identified best project management practices to improve design. Equally, Chang and Ibbs (1998, 1999) developed measures and levels for evaluating consultant performance. Levitt *et al.* (1993, 1999) simulated project work processes and successfully predicted time and quality performance of design projects. More recently, Austin *et al.* (2001) have modelled the design chain in construction to establish key to-do activities involved in the process.

**Design team interactivity**

In the recent past, engineers worked in centralized design teams, where individuals working on the same project sat in adjacent cubicles, often described as the *down the hall* work environment. Designers and other team members could easily meet with one another to compare notes, share information, iron-out problems and co-ordinate activities. However, in today’s globally distributed product development environment, a company’s various divisions and groups are often located around the world. To complicate matters further, critical aspects of product development such as analysis and manufacturing are now typically separated from the design group and are increasingly outsourced. This practice is aptly reflected by the construction sector, where the norm is for one organisation to design the facility and another to build it. It is not unusual for a design company and its partners to be many time zones apart (Thorpe *et al.*, 1998). Situations whereby work on the same design project is undertaken in sequence round the globe to achieve a round-the-clock work regime have been known. The benefits of the traditional style of collaboration that once occurred in hallways or in offices amongst engineers are being replaced by *virtual* interaction as the demands of time-to-market and the increasing pressure to cut development costs are complicated by greater fragmentation of the product development process. While e-mail, fax, and voicemail are valuable components of the design office environment, these make inadequate substitutes for simultaneous real-time collaboration. Current technology in the form of *view and mark-up* solutions all claim to be collaborative but what they really provide is only a sequential view and mark-up process. Typically, electronic documents are routed by means of a workflow process to reviewers who view them at the desktop, add comments, and send the comments back to the designer. This is repeated in an iterative cycle until all changes have been processed, agreed upon, and the next revision of the document is signed off and released. This method may take quite some time and the process really involves very little personal collaboration. Many design companies are yet to develop sufficient capability on how to implement this simple *view and mark-up process*. Yet as designs become more complex and innovative products become more important in overcrowded markets, the added value of true collaboration cannot be overemphasised. When teams can easily share ideas and information and work together in collaborative sessions, the right people make better decisions in a fraction of the time and information about these decisions is immediately available.

**Distributed design in aerospace**

Within the aerospace sector, the scale of investments required to support new product developments are often beyond the capacity of any one corporate organisation. This necessitates extensive collaboration between several organisations. Morris *et al.* (2000) identify a growing trend whereby new aircraft design is predominantly undertaken by a distributed team of engineers from different companies and in different countries collaborating *virtually*. They further outline a system developed assist the will be running of such distributed working for designers. This is presented as a *Core Team* and a number of task-oriented *macro* teams comprising human and information resources. The project identified the implications of such a structure from the viewpoints of organisation, culture, decision-making, the role of information technology and the interfacing of the various tasks to the overall project management. The outcome of the project present evidence of the need for addressing the human and work environment aspects of these distributed design teams in order for the technical activities associated with the actual design to be delivered efficiently.

**Distributed design in construction**

Designing a building or facility within the construction sector naturally represents a collaborative effort among specialists from independent disciplines such as architecture, structure engineering, services engineering, cost engineering. These specialists have to make interdependent decisions to design the components of the various systems that make up the building or facility. For example, the decision of a services engineer to size the supply duct of a space depends, among other things, on the function of the space. The function of the space is a decision that is taken by another specialist, the architect. It is not uncommon for these two specialists to be located in different corporate organisations. They thus collaborate in temporarily structured team organisations in a distributed fashion to realise the required design project. Traditionally, physical meetings during which design details are reconciled underpin this arrangement in construction. Designers and design engineers are therefore schooled with the art and know-how for managing in such team environments. In virtual environments, a lot of the skills required for physical meetings, are not directly applicable and different skills and work orientation is demanded.

## RATIONALE FOR CROSS-SECTORAL COMMONALITY

The emergence of cross-functional teams has outpaced the understanding of how and why they work the way they do. Although cross-functional teams have improved new product processes in many organisations, not all work equally well, nor are all equally collaborative. A recent study of high technology-based industrial organisations showed that collaborative behaviours are difficult to learn, and seldom result from mere membership on teams (Pinto and Pinto, 1990). Pinto and Pinto (1990) further opine that some teams consisting of representatives from R&D, production, marketing, and other functional groups transform and adopt collaborative behaviours and accelerate new product development processes. Issues of inter-personal interaction and committing to a common agenda present a daunting challenge to others. The past ten years of furore over work teams have left managers and design professionals in a difficult situation. The need for and usefulness of teamwork (at least in certain process tasks including the design function) is clearly appreciated. But while the demands for high performance teams continue to increase, the ability to create and sustain them appears to have reached a peak (Perkins, 1993; Varner and Beamer, 1995). Cross-functional teams, which reflect distributed design environments, have emerged as a popular structural mechanism for managing new product initiatives in high-technology firms. It is argued that they hold the potential for better integration of diverse skills that exist in production, marketing, and other functional groups, required for new product development processes. According to Griffin and Hauser (1992), Burgoon *et al.* (1995) and Katz and Kahn (1978), building collaborative teams, even among highly qualified and technically people, is challenging because it requires participants to shed dated views, unlearn old habits, develop new theories of action, and adopt new behaviours. The rationale is that people thrown together into teams no more become collaborative in the short term than technology-driven firms become customer-focused overnight. As such ensuring that the collective capabilities of people across the organisation or in distributed teams are reflected in newly developed products will continue to represent a principal challenge to design teams. The nature of learning that occurs and the development that characterise the process by which groups of individuals transform into collaborative new product teams are often context based (Gupta and Govindarajan (1991). However, there are generic issues from different sectors that can provide lessons and benchmarks for improving the design process and its management, as well as the environment and nature of work designers have to confront. These generic features are best captured through a commonality analysis.

## EXPLORING CROSS SECTOR COMMONALITIES

The cross sector commonality analysis is looking at different characteristics that reflect in design processes and the work environment of design teams in aerospace and construction sectors. As an exploratory study, it is essential that basis for identifying such commonalities and their level of relevance is adequately structured to ensure that there is sufficient alignment in the outcome of the analysis.

## Research approach and method of analysis

The research is conducted in close collaboration with industrial partners and is supported by the EPSRC. The research agenda is driven by a steering group of practitioners and academics. The generic method for identifying and analysing commonalities adopted for the project is the *prioritisation matrix*. The matrix approach is a technique that lies at the heart of many QFD methods. By comparing two lists of items using a rectangular grid of cells, it can be used to document a team's perceptions of the interrelationships that exist, for various issues against a set of criteria. In a prioritisation matrix the relative importance of items in a list and the strength of interrelationships are given numerical weightings. The overall priority of the items of one list according to their relationships with another list, can then be calculated. The technique is well established and interested readers are referred to other sources that provide a more comprehensive coverage (Checkland, 1981; Cross, 1989; Brassard, 1994). The prioritisation matrix should allow team members in design environments to collectively define common options using a systematic approach to compare choices. This is achieved by selecting, weighting and applying a set of defined criteria to listed issues that are reflected in the design environment and processes.

## Applying the technique

To apply the technique the following procedure was adopted.

1. Definition and compilation of the target issues
2. Brainstorm of compiled list of criteria to develop consensus on both criteria and issues
3. Placing all criteria on the Y-axis and X-axis of a matrix as depicted in Figure 1 and weighting each criterion against another. This is undertaken for the third order level of issues, and the exercise is performed separately for each of the first order level issues listed in Table 1. Table 1 excludes the third order.

**Matrix for prioritisation analysis (Issues versus criteria)**

| Criteria/Issues | A | B | C | D | E | Row Total | Rel. Dec |
|---|---|---|---|---|---|---|---|
| I | 1 | | | | | | |
| II | | | | | | | |
| III | | | | | | | |
| IV | | | | | | | |
| V | | | | | | | |
| VI | | | | | | | |
| | | | | | Grand Total | | |

Value cell 1 = (Criteria weighting of A) * (Issue rating of I)

Figure 1: Prioritisation matrix

Starting with the vertical axis each criterion is compared to the criteria on the horizontal axis. The following weighting system is adopted for undertaking the exercise.

1 = Equally important

5 = More important
1/5 = Less important
10 = Much more important
1/10 = Much less important.

By totalling all horizontal rows and for each weight a relative value of criteria weighting is established.

The prioritisation is undertaken by creating a matrix for the issues. For each criterion a comparison of all issues is undertaken to establish its rating.

A summary matrix is created by placing the criteria on the X-axis and the issues on the Y-axis.

Compare all the issues with the criteria. For each cell, multiply the criteria weighting with the issue rating. Calculate each row total for each issue result across all criteria. Calculate a relative decimal value. To make proper decisions compare these decimal values.

The results are employed to select the issues of commonality across the sectors involved in the study.

**Subsequent phases of the study**

The next phase of the project involves defining the criteria for prioritisation and their relative weightings. This would be achieved with the involvement of the project's industrial collaborators as well as consultation with an extensive group of designers who are not directly involved with the project. This phase will be followed by the actual prioritisation, to lead to the selection of commonality features.

## SUMMARY

This paper is based on preliminary outcome of a research project exploring ways for improving the working environment of designers who operate in distributed teams. It can be appreciated that the influence of ICT tools is fostering a shift in the way designers will work into the future. Whilst their current skills would still be relevant in the emerging work environment, additional skills and know-how become apparent. These additional skills are predominantly human and social oriented. The paper has explored how technology is influencing the design environment of distributed teams including the use of groupware and extranet-based collaborative workspaces to aid designers operate in multi-participant, distributed projects. It explored a number of functionality issues involved in such a workspace and introduced an analytical framework for generating commonality factors from two sectors that could serve as support information for productivity improvement of designers who operate in such distributed environments.

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