PROCESS IMPROVEMENT OF THE BUILDING SERVICES ENGINEERING INDUSTRY: THE TRANSATLANTIC CHALLENGE

Charles Fowler
University of Reading, Reading, UK

Abstract
Currently, the UK construction industry is under great pressure to make radical improvements in its productivity and cost performance without lowering the quality of the finished product. The industry must thoroughly evaluate its processes as it moves from a base in traditional crafts to a value for money, integrated production process encompassing the whole supply chain. In response to this challenge, the best practice production techniques and processes of the building services engineering industry in the US were identified and appraised for their potential application in the UK. A typical new building in the USA may contain a higher level of engineering services than its equivalent in the UK; its construction is at the same time considerably less expensive.

The visit, sponsored by the UK Department of Trade and Industry, took place between 24 November and 7 December 1996. Meetings were arranged with a variety of construction professionals from different areas, from Pittsburgh to San Francisco via St Louis, Chicago, New York, Houston and Denver. The group recorded its findings, and this paper discusses their relevance to the UK industry. Recommendations are given in the form of an Action Plan by which the UK construction industry may in the future maintain its high quality while increasing its productivity and cost effectiveness.

Keywords: building services engineering, process improvement, productivity

Charles Fowler is the leader of the Reading Production Engineering Group, Department of Construction Management & Engineering, University of Reading, Reading, UK.

BACKGROUND

Overview

The boom of the 1980s produced a great momentum for improvement in the construction industry. The best UK performance at that time was better than the best in the US (the international benchmark), but the US continues to boast a higher average performance (Bennett and Gray 1992). The UK needs the consistent achievement of its best performance rates, in order to enable it to acquire both the status of international benchmark for performance in construction and a sustainable international strategic and competitive advantage. Recently, a number of authors, including Latham (1994), have focused upon satisfying the business needs and requirements of the construction industry's clients. Low interest rates and low inflation provide the primary client motivation in the UK, and the industry must therefore respond by examining every aspect of its operations and efficiency; clients have seen what is possible and will use this experience to press for better performance. Pressure is now being applied to the construction industry for major increases in performance, value and certainty. Against this background, the industry must improve its efficiency.

W. Edward Deming, the American authority on production management, has said repeatedly that over 80% of an organisation's problems are due to failures in management. If this is true of the UK construction industry, it will be necessary to analyse and re-define the way in which it is co-ordinated and integrated. It must move away from the task driven, functional control of a project towards a highly focused and cohesive project process view. Traditional work processes and operating procedures, derived from a previous era and culture, can result in long cycle times, low quality, high inventories and a generally poor response to client needs (Davenport and Short 1990, Hammer 1990).

Contemporary construction practice largely involves assembling predetermined components in predetermined locations. The increased use of manufactured components has exacerbated the problems of managing the construction process. The integration and management of the sequence of assembly processes suffers from three, often conflicting, objectives: those of the design team, the site assembly production process, and the company itself. This conflict can be overcome by re-designing the management and organisational functions. There are two other major problems in the UK construction industry: firstly, the level of detail required in the design of the building, and secondly, the skills and experience gained on site, which are typically not captured and therefore not directly transferred to the next project.

The increased use of specialist trade contractors' input has meant that a simple separation of design and construction is impossible. However, specialist trade contractors and professionals who work under a construction management procurement system are able to maximise their potential, bringing considerable knowledge to bear at the inception of the project, alongside the design team. This in turn means that the expertise of the specialist trade contractor must be developed in a professional way. Moreover, to build quickly and efficiently requires a production environment of certainty. Consistency, simplicity and automation are needed not only within the project, but also from one project to the next. This can be achieved only by addressing the manufacturing and supply chains of construction projects, that is, specialist trade contracting.

More than ever before, the UK construction industry is being pressed to make radical improvements in its productivity and cost performance without lowering the

quality of the finished product. This will be possible only if designers, suppliers, construction managers and clients all work together and adopt a unanimous strategy of business process improvement and change. For this to happen, both the construction processes and the products of each specialist trade sector must be comprehensively evaluated.

The US experience

A typical newly constructed building in the USA can contain a significantly higher content of engineering services than that which is commonly found in the UK. The USA's mechanical, electrical, plumbing and fire protection industries have had to develop to meet the ever advancing demands of the market. Moreover, typical buildings are constructed considerably more cheaply than comparable buildings within the UK, partly as a result of better supply chain integration. Additionally, the climatic variation facilitates the rapid study of a variety of both heating and cooling services engineering systems. It was therefore appropriate to study the US building services engineering industry.

Mission aims and objectives

This project sought to appraise the best practice production techniques and processes of the building services engineering industry in the USA, and to determine how they might be reengineered for the UK. The mission therefore explored and reviewed the US building services engineering sector and analysed best US practice in order to foster the conditions most favourable for step increases in production efficiency. seeks to formulate a strategy for sustainable performance improvement and client value enhancement in the UK building services engineering sector. This paper discusses their relevance to the UK industry. Recommendations are given in the form of an Action Plan by which the UK construction industry may in the future maintain its high quality while increasing its productivity and cost effectiveness.

METHODOLOGY

An approach based on the methods that the Japanese have used to analyse and improve their manufacturing industry has been employed, involving the development of an Ishikawa (fishbone) diagram; the motivating forces in each branch were first identified, and then the barriers to performance. It becomes clear that building services engineering is a complex process with many inputs. Limitations were recognised, however: the diagram does not include the associated procurement and contractual environment, which was analysed by the team members before undertaking the mission and which are reviewed later.

Once the problems had been identified, force field analysis was used to weight the factors inhibiting change against the factors which can facilitate change while minimising effort and disruption (Prokopenko 1987). Any given level of production is a balance or equilibrium between impelling forces and restraining or impeding forces. It has been found that most success is achieved by removing the impeding forces, as trying to add pressure only results in increasing resistance. The team members therefore developed a force field diagram for the building services engineering industry to determine the issues of concern when visiting the US.

THE US CONSTRUCTION INDUSTRY

Overview

Constructed facilities are essential for all aspects of human activity, and the USA is no exception. "The efficiency and the quality of America's constructed facilities [are] of paramount concern for they truly determine the quality, efficiency and effectiveness of economic activity and, hence, relative competitiveness in the global marketplace." (CERF 1994). Indeed, the construction industry is:

- a major employer of the nation's workforce
- a major consumer of raw materials
- a key to environmental well-being, associated with 1/3 of all energy (2/3 of all electricity)
- a key to the nation's work environment, work productivity, safety and health
- a global competitor with international market share.

It is well known that the US construction industry is highly fragmented. Over 80% of firms are very small with fewer than ten employees; two-thirds have fewer than five. This represents a significant barrier to innovation within the industry, with only a few firms able to carry out significant R&D. Moreover, no firm in the construction sector has been able to absorb the risk inherent in the pursuit and development of innovation. As a result, the US industry lags behind other business sectors in R&D investment, as in the UK. However, the investment taking place is highly focused and trades contractor led. In this way, the US construction industry has remained efficient.

Innovation in manufacturing processes, materials, design, procurement and costing practices has transformed many US industries, making them more successful as national and global competitors. The goals set for construction over the next two to five years by the National Science & Technology Subcommittee on Construction and Building are extremely ambitious. They include:

- 50% reduction in project delivery time
- 50% reduction in operations/maintenance costs
- 30% increase in facility comfort & productivity
- 50% fewer building-related illnesses and accidents
- 50% less waste and pollution
- 50% greater durability and flexibility
- 50% reduction in job-related illness and accidents for construction workers

Enormous emphasis is being placed on the role of technological and management innovation in removing the barriers to achieving these goals within the US construction industry. The key point to note is that the US construction industry believes it must improve its productivity and cost performance very significantly from its current levels.

Construction industry characteristics

There would appear to be two distinct sectors of construction work in the US, Government or State funded (Federal) and privately funded. Whilst most of the fines visited undertake work in both fields, the greater part of their work relates to the privately funded sector. Contract awards for Federal funded projects are always secured by means of competitively tendered bids, and a low compliant bid invariably secures the contract. However, contract awards for privately funded projects can be via a route of competitive tendering, negotiation, or any combination, and they are shortlisted primarily on an 'experience, especially with the same client, and competence first, and

fee later' basis. This inevitably leads to much shorter tender lists than are typical within the UK.

The construction system in the US is highly geared to delivering the product to the client in the most efficient and timely way. Unit labour costs are very high compared to the UK and so the system is designed to utilise labour as efficiently as possible. This is in contrast to the UK's design led approach with costs held down through the Government's historically tight control on 'inflationary' labour rates. Moreover, the US system of regulation provides, by implication, an essential framework which requires certainty of decision. This applies initially at the point of obtaining building permission. At the other end of the process, a building cannot be occupied unless all the statutory certification has been received, for instance, elevator, boiler and fire escape permits have been issued. This has the effect of ensuring that the close-out is performed rigorously and precisely.

Americans tend to design very simple, straightforward and proven systems to contain the very high input and operation costs. This approach tends to deliver uniformity of product and performance. However, if the project demands are complex or the design requires unique solutions, the tried and tested US system is not used and the results are very expensive. Planning restrictions are minimal, and plant can be sited at convenient locations regardless of aesthetic concerns. Similarly, the building shape and finishes can be changed with minimal consultation, approval, or bureaucracy.

MISSION FINDINGS

Process focused design management

All design activity is focused upon establishing and controlling the building shape, area, finishes and services content, complexity and life expectancy, which are the key drivers in determining the cost parameters. There are typically four stages of design:

1. Pre-design: described as the information gathering and concept stage. The client involves the architect and the CM to provide cost and buildability advice. The costing exercise is undertaken in parallel with the basic concept design, often using parametric costs for guidance. There are few specialist cost consultants and no quantity surveyors.
2. Schematic Design: when options are being considered, architectural schematics are completed, and coatings evaluated. A Guaranteed Maximum Price (GMP) may be established at this stage to fix the project budget and thus the viability of the project. A value engineering exercise may be implemented subsequently (post contract) to maintain the GMP.
3. Design Development: drawings and specifications are prepared in line with agreed and signed off schematics and GMP. Orders for subcontractors may be defined by negotiation or competitive tendering at this stage.
4. Construction Documentation: finalised and specifications are completed which detail the extent of the works. These may be utilised to secure competitively tendered bids (particularly on Federal contracts) or form basis of final GMP negotiations or firm tendering.

The Building Owners Management Association (BOMA) provides a classification system for commercial property. For example, for a building to be considered of class A, it would need to be of a high standard and in a good location. These classifications are useful in determining 'benchmark' standards which dictate the extent of services, quality of services and finishes. Moreover, letting agents have a constructive say in the

finishes and the service content of buildings, mindful of client budgets and lease parameters. Such agents appear more knowledgeable than their UK counterparts and dictate only affordable standards, recognising the need to balance construction costs against rental returns, lease periods, retrofit costs, and so on. Similarly, clients appear to have an acute awareness of 'cost vs. value vs. return' and hence carefully dictate their requirements to the professional team on the basis of payback periods.

Client focused

The Americans act in a very dynamic, often a seemingly aggressive, way to ensure that a good brief is established at the outset. The client's business and requirements are identified and fully appreciated by everyone, from the initial writing of the brief through design and construction until handover. The emphasis upon a client focus is seen to result not only in repeat order clients but also in a reduction in wasted time and effort on the part of the designers, through solving problems which are irrelevant to the client's needs. It is recognised that design development will occur, but that it should be controlled and the client continually informed of the developments. After the appointment of the CM, the focus of the project shifts to the management of the detail design and construction process, in the light of the need for value and production efficiency.. The design is reviewed by the CM, and the services engineering contractors use their skills to rationalise the design within their known skills base. At each stage the teams start with a common understanding of the goals and a have common vision. Value engineering is widely used, not just as a means of cost reduction but in order to assess the efficiency of the whole project, including running costs and life cycle maintenance. No universal codes or standards were obviously employed, but general use was made of the standards set by ASHRAE.

Contribution of teamwork to design and construction

There is in the USA a widespread recognition of the particular expertise brought to the project by each of the various groups, including building services engineering contractors, and an awareness of the need to maximise their input. The scope of work is controlled by a much greater awareness of custom and practice. US design fees are low, and therefore the input from the design team is more precisely focused. The UK is moving towards this through fee bidding, but without any correlated change in the expectations of clients, CM's or trade contractors. There has been a big shift in the US to design by the services contractor. This is happening in the UK also, but US design expectations are lower, certainly on normal commercial buildings.

Part of the task of the CM is to make everyone aware of the cost and time framework of the project. It is understood that there will be change. Modifications to and development of the original concept will occur, but in an open and informed way; the client is continually kept up to date with the development of the project. The CM ensures that everyone will use their best endeavours to keep to the original objectives. Relationships between all parties are based on trust and mutual respect and the desire to avoid conflict.

Cost control and change management

Cost in the US is seen as everyone's responsibility. Initial budgets are set by the CM, usually working together with the designers, and are based on the current capabilities of the industry, so that there are few surprises in project scope or specification. At the construction stage, power is devolved to the CM's project managers who have control of the budget for a specified area of the work. Changes in scope are priced and agreed before implementation, either by the CM and client or the CM/services engineering contractor and client. A claims approach is avoided throughout the project, as changes

are agreed progressively and budgets are amended throughout. The client is kept informed, on a daily basis if necessary, to ensure there are no surprises. The contract provides for automatic preliminaries so avoiding the difficulties of resolving the claims for costs in conjunction with extensions of time that are so prevalent in the UK.

Simple and efficient documentation

There is far less documentation, both for contracts and in codes and regulations, than in the UK; such documents as there are tend to be short and explicit. Contracts identify both problems and solutions, and reference is constantly made to the industry's norms and standards. Specifications are both comprehensive and simple to understand, being carried over from one project to the next. The most successful contracts cited were those in which client requirements were fully understood by the professional team and clearly defined down the line to the contractors.

Standardisation of technology

In particular contrast to the UK, technological innovation in the US is limited, and everyday facilities are built within a well-known technological set. ASHRAE standards are used as the default set by their members to provide stable and workable solutions. The basic set develops over time, but there is no radical change from one project to the next. This stability allows for incremental improvement in practice, cost and efficiency.. When designers step outside the accepted norms, cost prediction is very uncertain and usually cost-plus. US building codes are also drawn up to protect both users and the construction process, and are neither legalistic nor complex in their drafting.

Simple nature of the product

On smaller value contracts, contractors may be responsible for more than one package. However, on larger value contracts there is no evidence of multi-service installations. Contractors are not generally both mechanical and electrical, but may assume responsibility for mechanical, plumbing and ductwork. Service packages are typically divided into the following five categories:

- Mechanical: heating and cooling pipework and associated plant
- Plumbing: water services pipework, sanitaryware, drainage and rain water pipework
- Ductwork: ductwork, with or without air handling units, fans and associated air movement components
- Sprinklers: sprinkler pipework (little evidence of stored water)
- Electrical: all electrical installations

There were limited examples of specialist packages being stand alone on larger value contracts e.g. controls, commissioning.

Summary

The US system, although it appears to be very tough, is based on the assumption that everyone is in business to benefit and should be treated fairly. Negotiations are exacting while the parameters of the work are set, allowing service engineering contractors to maximise their input. This is to their own advantage and also to that of the client. A tough negotiation is often softened by a return for further concessions, that is, what is the cost of no problems? Terms of payment are strictly adhered to throughout the industry, and 21 days is normal. Strong 'encouragement' to respect the contract terms of payment comes from the 'lien laws' which exist across the US, whereby anyone who has delivered anything to site in accordance with their contract can issue a 'lien' on that site if they are not paid according to the terms of their contract. Regardless of the reason, such as paid-when-paid clauses, a lien involves the sequestrating of a project's assets to

enable all outstanding financial sums to be realised. Project managers and owners go to great lengths to avoid such damaging action, by ensuring that payment terms are adhered to.

The size of contracting organisations is a feature of the chosen category of work, location and workload. If companies have an acceptable reputation and bonding facility, they can accommodate large value contracts at short notice by hiring additional operatives (and staff). When contractors are not being utilised, the US modus operandi negates the requirement to carry high resource costs, and this, taken together with the easy recruitment of operatives and lower supervision ratios, enables more flexibility in the control of overheads and hence a lower average overhead cost base. In addition, operatives have strong union ties, and the majority of projects are awarded on a 'closed' (union labour) basis. On the other hand, the unions organise and manage vocational training for the operatives, thereby improving their individual opportunities for employment.

In contrast to the UK, US contractors' operating costs show the following features:

- lower net employment costs
- fewer company vehicles
- less holiday - staff have 1 week increasing to 3 after qualifying period; operatives operate holiday pay reduction scheme but do not take long holidays, i.e. there is no cost to company
- lower premises costs
- lower fuel costs - impacts at all levels
- lower expenditure on commercial, purchasing, estimating, safety and QA staff
- contract specialisation in selected trade categories limits the requirement for back up staff.

ACTION PLAN

Discussion

Many reasons have been given as to why project costs should be lower in the US than in the UK, often by as much as 30%. Nevertheless, the cost advantage is outweighed by other factors. Material costs are cheaper in the US than in the UK, but labour costs are higher and the heavy unionisation of the workforce leads to demarcation problems in the major cities. Yet, even though US labour costs are approximately double those in the UK on a straight exchange rate basis and material costs are lower, the vast difference in installation cost is not fully explained.

There are two significant features in the US: the first is better and more productive use of labour at the workface with less wastage. There are also cultural differences in the attitude of the workforce and the apparently close co-operation of the different trades. The second factor relates to installation, in the acceptance and use of proprietary and simple fixing detail which gives the better productivity highlighted above. Other cost factors relating to pre-installation need to be further investigated.

The use of 'standard solutions' with regard to services engineering systems and the formation of a brief related to the client's financial constraints eliminates, within the US, the 'over-engineering' proclaimed as a significant UK cost factor. A comprehensive brief reduces design wastage, that is, there is one design based on explicitly defined performance parameters, and everyone has an appreciation of the client's overall goals and objectives. The principle of designing what is 'suitable and sufficient', rather than to the highest quality regardless of the cost implications, produces a services engineering

design which is more 'dollar driven' and relates better to the project. This approach avoids the 'ready, fire and then aim' mentality often experienced on UK projects.

The UK industry's approach to making highly individual buildings more affordable is to follow procurement and contracting practices which are, in the long term, counter-productive and which destroy any sense of teamworking culture within the project as witnessed in the US. A process orientated approach to design and construction must be implemented if the economies which are being sought are to come to fruition.

The recommendation is that the differentiated design philosophy favoured by UK culture should be maintained, but that a production system should be developed so that value can be measurably improved from the use of integrated supply chains.

The design and construction of UK building services is clearly a complex process which is technologically sophisticated. In response, the services sector has adapted to cope with high levels of uncertainty and complexity, whilst retaining flexibility and an innovative approach; ultimately, it is of world class capability. However, if the industry is to capitalise upon this, overcoming the barriers to efficient engineering is a fundamental requirement. The challenge is to change the long-established and counterproductive insularity of the UK construction professions and consequently the building services engineering industry itself. If this is not achieved, any attempt at world-wide competitiveness will be undermined; action is both necessary and urgent.

Table 1 outlines how the US building services engineering industry has overcome many of the barriers to efficiency in the UK. These actions form the basis for an action plan for the UK industry so that it can achieve significantly higher levels of client value for money and/or cost reduction.

Clients must be able to fulfil their business needs quickly and effectively. For this to occur with services engineering, the industry must be able to guarantee the delivery and reliability of their systems to mutually accepted and agreed standards. A UK strategy is necessary which builds upon the requirement of a world class capability, whilst allowing the industry to confidently guarantee its products at affordable prices.

For such a challenging task to become reality, it is most important to manage the early decision process, in order to avoid many of the later problems. The production of better quality and more exacting design and construction briefs transforms the project from the mere satisfying of vague requirements, to the achievement of a value added constructed facility. For this to be possible, a culture of teamwork, trust and mutual appreciation of each other's roles must be embodied within the definition of the product required. Ultimately, this stems from the specification employed.

A definitive specification: recommendations

In attempting to achieve an efficient project solution in the UK, a wide variation in specifications between projects has arisen. Moreover, in trying to reduce the complexity of their own task, engineers have adapted these specifications and consequently produced an enormous range of requirements which is causing the supply side of the industry major problems in constantly adapting to new sets of demands. The US system shows significant benefits from a high level of consistency. One step for the UK is for the relevant Trade Associations to collaborate and produce a definitive, simple and straightforward nationally applied specification, which would enable every services installation to be guaranteed. For such a specification to be widely accepted, it must originate from building services engineering contractors and their suppliers and link together the whole supply chain.

The UK response

Table 1 **U**S model solutions to remove barriers to efficiency in the UK**.**

UK Barrier to be removed	**US Action to overcome barrier**
Lack of performance incentive	Greater use of incentives at all levels Reduce design duplication and redesign
Inadequate communication between participants	Shared project goals and objectives with high level of communications visibility
Lack of ownership of defects	Removal of design v. construction attitudes embodying mistrust and suspicion Trust trade contractor competency
High level of team fragmentation	Dispel any lack of trust and encourage mutual respect between all project participants Create teams and focus on team building and teamwork
Poor co-ordination of commissioning phase	Adequate time and resources provided for commissioning
Lack of understanding of services engineering requirements and issues	More time and better design information during bid preparation period Education of client, CM and designers to enhance design management skills
Poor integration of supply chain	Involve CM early in the process Removal of "them and us" attitude
Lack of profitability	Design buildings for use, i.e. appropriate quality and provisions
High level of non-standard components	Standardise design and equipment Reduce "back of house" requirements Removal of "design is all" attitude
Use of inappropriate management methods & techniques	Greater emphasis upon cost vs. value vs. return Performance specification using consistent requirements allows competitive resource based pricing by trades Better on-site cost management and pricing / negotiation of change orders to avoid claims Involvement of trade contractors in decision making process
Late procurement of services engineering skills & knowledge	Early trade contractor involvement
Poor logistics systems	Greater focus upon efficient operations on-site
Lack of clarity in the construction brief	Ensure a comprehensive construction brief Trade contractor involvement in design phase
Inappropriate contract conditions	Greater use of pre-bid meetings Better documentation and design information to allow more accurate bids and to minimise charges Release from bonding on clearance of punch list / client acceptance / handover
Lack of clarity in the design brief	High emphasis upon "front-end" issues Ensure a comprehensive design brief
Lack of investment	Investment in incremental methods of production improvement by Trade Associations
Use of inappropriate procurement methods	Greater use of pre-qualification and vetting procedures of contracts
Impractical legislation	Rationalisation of regulations and legislation
Impractical design codes	Rationalisation of codes by Trade Associations

This new approach to a national specification could be process and performance driven and structured as a system with three levels. The lowest level of specification would form the 'standard' or default specification and comprise those aspects most commonly required but only to a good but basic standard. The next level of specification might set a higher standard of services engineering. It would cost more and have additional production issues. For fully customised projects, a third level of specification could be employed, which might be at the leading edge of innovative engineering practice. Coupled to each level of specification should be target benchmarks for cost and project productivity either based on the best UK performance or set at world class levels of performance. Thus it would be possible for both client and design team to understand fully where money is being spent, and the impact of their requirements and ambitions.

The specification should cover:

- Targets for production and cost performance
- A clear and agreed set of standardised system performances that can be achieved and their relative production advantages
- A nationally accepted standard schedule of equipment specifications which can be guaranteed by the manufacturing industries
- A guide to finishes and tolerances for each of the standardised systems taking into account their relative production advantages
- Clear production process guides and workmanship practices which consider the implications of systems integration against which the standards are being set

Process embodied procedures: recommendations

The above specification should be complemented by a set of process embodied procedures aimed at establishing services engineering production, such as:

- A detailed cost model that can differentiate between the implications of even minor variations and additions to the simple approach, so guiding designers and engineers to the true cost of the complexity that they are adding by tailoring individual services engineering systems to specific needs. The default model would provide the most economic and fastest construction design at the benchmark construction rate.
- A robust design management philosophy that is driven by value, simplicity and appropriate quality for the project. Emphasis should be placed upon the establishment of a comprehensive brief and the production of better and more informative construction information. All of the necessary engineering skills which allow the design to be implemented with greater cost effectiveness need to be assembled at an early point in the project process.
- A teamworking approach based on trust, which is focused on delivering the completed project to the client in the most efficient manner should be established. A claims approach should be avoided. Changes in design, specification or installation methods need to be recognised as inevitable. As the project progresses all variations need to be costed and agreed beforehand, and paid as the work progresses, with the client being kept fully informed.
- A two stage procurement approach to the securing of the building services engineering contractor recognises and enables the input of the specialist, at the scheme design stage, to maximise the design for production. The key is the recognition of the production and process optimisation skills of the building services engineering contractors and the need to restructure the roles and scope of the design team to maximise this input.

CONCLUSION

The conclusion from this study is that the UK's building services engineering industry is based on a high capability to produce tailored and specific solutions, but that the production processes are currently inefficient and therefore need rapid review. Until the change is implemented, through improved standards of management, co-ordination and integration within the design and supply chain, buildings will continue to be produced inefficiently.

To implement these recommendations will require a radical redefinition of the relationship between consultant services engineers, the demand side of the industry, and the supply side. UK design competence already has a major standing in the world. This should not be abandoned. In fact it needs to be developed to embrace a total understanding of the production and process issues arising from innovative design solutions. To achieve this, the demand side and the supply side should develop joint educational programmes to achieve a mutual understanding of each other's needs. This is over and above project based partnering, which still must occur, and which is designed to produce a climate of mutual trust and constantly developing capability.

REFERENCES

Bennett, J. and Gray, C. (1992) The Construction of Broadgate, in *The History of Broadgate,* ed. Hunting, P., Stanhope plc, London, pp. 48-60.

CERF (1994) *Innovation in the US Construction Industry: An Essential Component for America's Economic Prosperity and Well-being,* A Construction Industry White Paper, CERF; Washington DC.

Davenport, T. and Short, J.M. (1990) The New Industrial Engineering: information technology and business process redesign, *Sloan Management Review,* Summer pp. 11-27.

Hammer, M. (1990) Reengineering Work: don't automate, obliterate, *Harvard Business Review,* Vol. 4, July-August, pp. 104-112.

Latham, M. (1994) *Constructing the Team,* HMSO, London.

Prokopenko, J. (1987) *Productivity Management,* ILO, Geneva, p. 148.