Design and Design Management in Building Projects: A Review

Rıfat Akbıyıklı[1], David Eaton[2]

Abstract

Design is that activity, largely executed by consultants and in-house disciplines, which translates the aspirations of the Client, into a series of documents, both drawn and written, which in combination can be used to procure the manufacture, assembly, commissioning and operation of both building elements and the project as a whole. Management of the design process is planned to ensure that the project requirements have been correctly interpreted in an agreed brief, with a consistent format of technical verification reports and design analysis audit trail, as set out in the project plan. This paper, based on a literature review, examines traditional design management and design and construction as an integrated system. The paper is an introductory part of an ongoing project to map design and design management practices in architectural and civil engineering practices.

Keywords: Design, Design Management, Design Integration, Procurement Routes, Teamwork

1 Sakarya University, Department of Civil Engineering, Esentepe Campus, Adapazarı – Sakarya, Tel: 0264 2955740, E-mail: rakbiyikli@sakarya.edu.tr
2 School of the Built Environment, 4th Floor Maxwell Building, University of Salford Salford, Greater Manchester, M5 4WT, United Kingdom, Tel: +44(0)161 295 5222 E-mail: d.eaton@salford.ac.uk

Bina Projelerinde Tasarım ve Tasarım Yönetimi: Bir İnceleme

Rıfat Akbıyıklı[1], David Eaton[2]

Özet

Tasarım, genellikle müşavirler ve şirket içi disiplinlerce yapılan ve İşveren' in amaç ve isteklerini hem bina ve hem de projenin tümünün üretiminin elde edilmesine, montajına ve onay ve teslimatı ile işletmeye alınmasında kullanılan çizili ve yazılı bir seri dokümana dönüştüren bir aktivitedir.

Tasarım prosesinin (sürecinin) yönetimi, proje planında öngörüldüğü ve ortaya konduğu gibi projenin gereksinimleri önceden üzerinde mutabakat sağlanmış olan ve uyumlu formatta teknik tahkik raporları ile tasarım analizinin doğru bir özet raporuna dönüştürülmelerini sağlamaktadır.

Literatür incelemesine dayalı olan bu bildiri, geleneksel tasarım yönetimi ile tasarım ve yapımını bütünleşik bir sistem olarak incelemektedir. Bu bildiri, mimarlık ve inşaat mühendisliği bürolarının tasarım ve tasarım yönetimi uygulamalarının ayrıntılı bir haritasının çıkarılmasına ilişkin devam etmekte olan bir çalışmanın başlangıç bölümüdür.

Tasarım bir kreativite (yaratıcılık) aktivitesi olarak vaka toplama ve özet ön bilgi toparlamadan ayrı bir süreçtir. Tasarım sentezi; projenin kalitesinin, maliyet planının, ihale elde edilmesinin ve yapım programlarının kurulabilmesi için kullanılmaktadır. Bu referans araçları daha sonra projenin iş ilerlemesi, maliyet ve kalite parametrelerine karşı sürekli olarak ölçülebilen performans parametreleri olmaktadır. Çeşitli çalışmalar, eksik ve hataların büyük bir yüzdesinin tasarım etaplarında alınan karar ve aksiyonlar nedeniyle oluştuğunu tespit etmiştir. (Cornick 1991) Buna karşılık zayıf bir tasarımın ise yapım aşamasındaki etkinlik seviyesi üzerinde çok etkisinin olduğu tespit edilmiştir. (Ferguson, 1986) Çağdaş yapıların artan karmaşıklığı, zaman (süre) ve kalite terimleri ile tasarımın performansının iyileştirilmesi için bir baskı unsuru oluşturmaktadır. Önemli olmasına rağmen tasarım prosesinin yönetimi için, üretim (yapım) yönetimi ve genel proje yönetimi için harcanandan daha az araştırma süresi ve çabası harcanmıştır. (Austin ve diğ. 1994; Koskela ve diğ.1994)

1 Sakarya University, Department of Civil Engineering, Esentepe Campus, Adapazarı – Sakarya, Tel: 0264 2955740, rakbiyikli@sakarya.edu.tr

2 School of the Built Environment, 4th Floor Maxwell Building, University of Salford Salford, Greater Manchester, M5 4WT, United Kingdom, Tel: +44(0)1612955222, d.eaton@salford.ac.uk

Tasarımın yönetilmesi zor bir süreçtir. Çok belirsiz bir çevre şartları içerisinde bazen belirli bir yıl süre alan binlerce karar, sayısız birbiri ile ilişkiler içermektedir. Ayrıca mimar, yapı mühendisleri, servis mühendisleri (elektrik, makine, havalandırma, tesisat) ve pazarlama mühendisleri gibi çok sayıda personele ihtiyaç duyulmaktadır (Powell ve Newland, 1994). Bu nedenle tasarım sürecinin karmaşıklık ve belirsizliğini minimize etmek için etkin bir planlama ve kontrol gerekmektedir. Zayıf iletişim, eksik dokümantasyon, yanlış veya eksik girdi bilgisi, dengesiz kaynak ve tahsisat, disiplinler arası koordinasyonsuzluk ve yanlış karar alma tasarım yönetimindeki ana problemler olarak belirlenmiştir (Cornick, 1991; Austin ve diğ. 1994, Koskela ve diğ. 1997).

Anahtar kelimeler: Tasarım, Tasarım Yönetimi, Tasarım Entegrasyonu, Satınalma Yöntemleri, Takım Çalışması

Introduction

Design activity is largely carried out by consultants and in-house disciplines, which translate the aspirations of the Client, into drawn and written media which can be used to procure the construction, commissioning and operation of the whole project. Design, as a creative activity is separate from the fact gathering and brief assembly process that precedes it. Design synthesis is used to establish the quality of the project, the cost plan, procurement and construction programs. These reference tools then become the performance parameters against which progress, cost and quality can be continuously measured. Studies have identified that a large percentage of defects arise through decisions or actions in design stages (Cornick, 1991) whilst poor design has a very strong impact on the level of efficiency during the production stage (Ferguson, 1986).

The increasing complexity of modern buildings has significantly increased the pressure to improve the performance of the design in terms of time and quality. Despite its importance, less research time and effort has been dedicated to the management of the design process, than to production management and project management in general (Austin et al, 1994; Koskela et al, 1997). The small relative cost of the design process when compared to production costs disguises its true importance for overall performance (Austin et al, 1994).

Design is a difficult process to manage. It involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, within a highly uncertain environment. A large number of design personnel are needed: architects: structural engineers; service engineers; and marketing consultants (Powell and Newland, 1994). The design process therefore needs effective planning and control to minimise the effects of complexity and uncertainty. Poor communication; lack of adequate documentation; deficient or missing input information; unbalanced resource allocation; lack of coordination between disciplines; and erratic decision making; have been identified as the main problems in design management (Cornick, 1991, Austin et al. 1994, Koskela et al. 1997).

Nature of Traditional Design Management (DM)

Construction design is a specialised and highly demanding form of problem solving (Pressman, 1993; Lawson, 1997) where Stakeholders' needs and requirements are conceptualised into a physical representation of procedures, drawings and technical specifications (Freire and Alarcon, 2000). It is a dynamic and complex multidisciplinary process, performed in a series of iterative steps to conceive, describe and justify increasingly detailed solutions to stakeholders' needs (Sterman, 1992; Ogunlana *et al*, 1998; Baldwin *et al*, 1999). It is the key project process (Morris *et al*, 1999; Cockshaw, 2001), defining up to 70% of the final product cost (Kochan, 1991) and adding value by delivering: functionality; quality; enhanced services; reduced whole life costs, construction time and defects; while delivering wider social and environmental benefits (Treasury Task Force, 2000; Prescott, 1999).

Effective design management ensures that *all* project requirements have been correctly interpreted in an agreed brief, with a consistent format of technical verification reports and design analysis audit trail, as set out in the project plan. In that respect, DM is an emergent professional discipline which separates the management function of a project's design phase from the design function. It is increasingly important in construction projects (Gray and Hughes, 2001). It is closely aligned to project management, to provide a fully co-ordinated project, on time, meeting all stakeholder needs by co-ordinating, controlling and monitoring design activities while interfacing with other project and external parties. It is typically realised by a design manager or team of managers depending on a project's size and complexity.

Design planning

An effective and workable design programme is essential to exert managerial control over the design process and improve co-ordination between parties (Austin *et al*, 1994). The low priority of design in project planning is attributed to construction accounting for the majority of the project costs. It is now recognised that construction efficiency and costs are heavily dependent on the quality of the design solution (Austin *et al*, 1998) and availability of information and hence the quality of the design programme. Newton and Hedges (1996) claim there is a poor understanding of the interdependency of information flows because separate disciplines do not understand how their work contributes to the whole, causing a fragmented approach to planning. The identification and co-ordination of cross-disciplinary information is left to the expertise of the design planner or project manager (Baldwin *et al*, 1994). This creates implications for the co-ordination of discrete design disciplines and general process control. Another facet of poor design planning is that resource allocation is often unbalanced (Cornick 1991, Austin *et al* 1994, Koskela *et al* 1997a). This can cause initial delays (Koskela *et al* 1997b; Love *et al*, 2000) but can also escalate into further problems.

Information management

The principal management activity of any project is the processing of information (Baldwin *et al*, 1994; Heath *et al*, 1994), yet in the construction industry this is poorly performed (Latham, 1994; Kagioglou *et al*, 1998). Management is predominantly through schedules (Ballard, 1999) programmed to achieve the required information release to contractors (Austin *et al*, 1998). It does not consider the internal logic of the design process –poor planning is a factor in poor information management (Formoso *et al*, 1998). As a result information transfer is not properly controlled; designers do not have the right information at the right time and are overloaded with unnecessary information (Huovila, 1997). This creates the risk of failure of design tasks, deficient analysis and wrong decisions with potential waste in the process due to rework (Huovila *et al*, 1997; BRE, 1995; O'Brien, 1997; Frankenberger & Badke-Schaub, 1998). The erratic delivery of information and unpredictable completion of prerequisite design quickly results in the abandonment of design planning (Huovila *et al*, 1997), therefore perpetuating a cycle likely to create further difficulties.

Design Changes

Traditional construction is *sequential* with a low degree of collaboration between different domains. Over-specialization of functions leads to significant problems. Primarily, these result from the separation of design, engineering, and production and the inability of these functions to communicate effectively.

Design changes are a significant problem having large administration costs (Machowski and Dale, 1995), accounting for 40-50% of total design hours (Koskela, 1992) and even in well-managed projects can cost between 5 to 15% of total construction costs (Morris *et al*, 1999; CIDA, 1994; Burati *et al*, 1992). When measured by cost, design caused defects are the biggest category of construction defects. Of design caused defects, those originating from missing coordination between disciplines form the largest category. Love *et al* (2000) highlight that such costs should be even higher as they do not represent the latent and indirect costs, nor the disruption of schedule delays, litigation costs and other intangible aspects such as buildability (Kagioglou *et al*, 1998). Morris *et al*, (1999) suggest that even well-managed projects led by industry leading managers, two-thirds by cost, of design changes are avoidable. This offers significant potential for improvement.

Newton and Hedges (1996) observe that traditional DM techniques cannot predict the effect of change on the design programme and fees. As such, it is difficult to determine all the possible change paths and select the best (Mokhtar *et al*, 2000). Thus, if current tools cannot determine the impact of design changes and human judgement is unable to account for the interactions that determine its outcome (Richardson, 1991; Sterman, 1992) then design changes are made without exposure to all potential impacts. Such inability to predict the impact of changes must be considered as a barrier to effective control of design changes and therefore management of the design process. If change control is improved then there is more chance of project success.

The management of design is problematic due to the following design problems:

- Poor briefing and communication;
- Inadequacies in the technical knowledge of designers;
- Lack of confidence in preplanning for design work;
- Lack of adequate documentation;
- Deficient or missing input information;
- Unbalanced resource allocation;
- Lack of coordination between disciplines;
- Erratic decision making;
- Lack of effective planning and control to minimize the effects of complexity and uncertainty. (Ballard and Koskela(1998) and Tzortzopoulos and Formoso (1999)

While sites can operate on a definition of quality as conformance to requirements, design must produce those requirements from identification of client needs! Many design decisions are reciprocally independent, making the management of work flow among the various specialists important and difficult. Early design stages are notoriously hard to evaluate and against progress milestones.

In general, the design phase, being one of the early phases of the project life cycle is found to be a major source of problems for the subsequent phases, even to the extent of undermining systematic management during construction (Ballard & Koskela, 1998) (Figure 1).

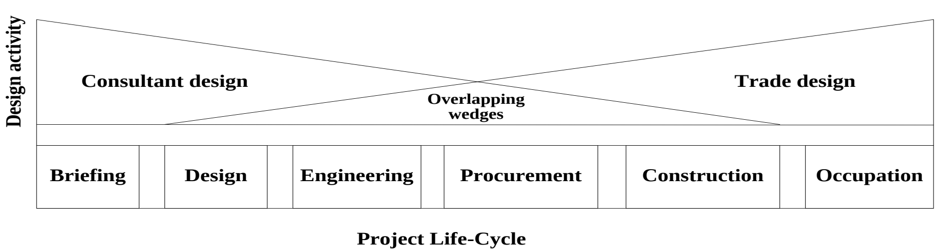

Figure 1. *Design Activity versus Project-life Cycle*

To overcome these problems, new methods of working and organizational structures which facilitate and integrate design, development and production are necessary.

Design and Construction as an Integrated System

Construction involves many people with different skills, knowledge and interests working together for a short period and then separating upon completion of the project. This creates problems for both the design and construction processes, due to the large number of interfaces and communication difficulties (Kagioglou *et al*, 1998). Therefore, while it is clear that the integration of design and construction is vital to project success – it is also a fundamental weakness in the industry (Egan, 1998). Integration during the design phase is *also* crucial. It prevents problems in subsequent phases, and is necessary for the development of suitable design solutions (Mitropoulos and Tatum, 2000) and ultimately to achieve client satisfaction (Ferguson and Teicholz, 1992).

The existing construction system consists of independent professionals - The *designer, contractor and client* relationship is a linear delivery system. These processes can also be viewed as an *integrated system*:

- *Design* is a process of defining a *client's requirements*, represented by detailed plans and specifications;
- *Construction planning* is a process of identifying *activities* and *resources* required to realize the plans and specifications as a physical reality;
- Construction is the implementation of the activities and resources to deliver a facility to meet the clients' requirements.

The two central aspects of an integrated construction system are:

- An underlying common data model to permit data integration between phases;
- System control mechanisms to integrate operational efficiency.

In an *integrated system* design and construction planning proceed simultaneously, examining various alternatives from both viewpoints thus eliminating the necessity of extensive revisions under the guise of value engineering. In order to support integrated design and construction, information must be shared, *and* managed to actively promote *integration.* The review of design and constructability can then be carried out concurrently as the project progresses seamlessly from design to construction. Design stage decisions are multi-dimensional - made by individuals often belonging to different organizations - combining factors ranging from the highly subjective to the perfectly objective. They are made over prolonged periods of time in an iterative manner and may be revisited weeks, months and even years after they were originally taken. There is considerable potential for misunderstandings, inappropriate changes, changes which give rise to unforeseen difficulties, decisions which are not notified to all interested parties, and many other similar problems. However, the concept of a truly integrated system cannot be realized whilst the owner assumes the traditional risk-reward dilemma. Alternative forms of risk transfer are a pre-requisite.

Design Stages and Methodology

The basic approach to design relies on *decomposition* and *integration.* Since design problems are large and complex, they have to be decomposed to yield sub-problems that are small enough to solve. Alternative ways to decompose design problems are:

- Decomposition by functions of the facility;
- By spatial locations of its parts;
- By links of various functions or parts.

Functional Design - The objective of *functional design* is to treat the facility as a complex system of interrelated spaces which are organized systematically according to the functions to be performed in these spaces in order to serve a collection of needs. The arrangement of the physical spaces is an iterative process. Selected rules or strategies (heuristic approach) are used in search of a solution. This approach is based on the following considerations (Hendrickson, 1989).

- Identification of the goals and constraints for specified tasks;
- Determination of the current state of each task in the iterative process;
- Evaluation of the differences between the current state and the goals;
- Directing the search towards the goals on the basis of past experience.

Structural Design - involves *synthesis* and *analysis.* Synthesis is *inductive* while analysis is *deductive.* Synthesis is more akin to *creativity* than to knowledge. The *conception* is *subjective* since there is no established procedure for generating innovative and successful alternatives. The *initial selection* relies on the judgment of the designer. Once selected it is vigorously *analysed* to ensure that it can sustain the demands of its environment. For traditional structures (E.g. office buildings), standard systems are derived from the past experience of many designers. However, in many situations, designs must be developed to meet particular requirements. The interplay of *structural form* and *materials* affects the selection of a *structural system,* which in turn may influence the *method of construction* (Figure 2).

Design Management Research

Design management research has focused on: design planning and controlling change (Austin *et al,* 1998); control of design activities (Ballard and Howell, 1998); managing the integration of design phase teams (Austin *et al*, 1999; Austin *et al*, 2001; Business Round Table, 2002); and collaborative working (Steele *et al*, 2001).

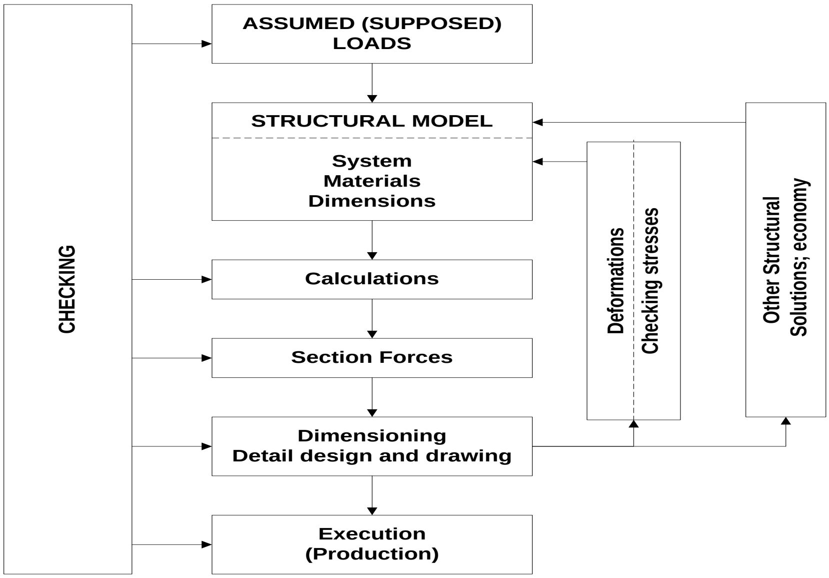

Figure 2. *Structural Design Flow for Buildings*

There is much material to draw on in terms of identifying problems but there are few practices on which research has been able to build. Work by Austin *et al* (1999), Cross (1989), Gray *et al* (1994), Gray and Hughes (2001), Kagioglou *et al* (1998) and Process Protocol 2; Lafford *et al* (1998), has influenced this research. Other industries offer significant work for adaptation to construction. Lean Production (Womack *et al*, 1990), and Concurrent Engineering (Sheath *et al*, 1996) are initiatives from the automotive, manufacturing and aerospace industries which hold valuable lessons for managing the construction design process. They offer useful guidance for improving the DM process in the construction industry. However, the construction environment is significantly more complex than manufacturing, automotive and aerospace industries and consequently such innovations require more development to be implemented successfully (Marosszeky & Karim, 1997).

New Paradigm - variability in the future has to be considered when trying to *envision* the design management. The properties of *adaptability* and self-correcting systems that evolve to meet change whilst respecting the *constraints of the environment* are *critical* to the *development and control of design*. A *paradigm shift* in *storing and communicating design* information has occurred. The *object model* allows *design* and *analysis* simultaneously across the *life of the project.* This shift implies a different way of thinking. The International Alliance for Interoperability (IAI) universal object-oriented data model (IAI, 2011) suggests that a *holistic* or *systems approach* to the process is necessary to make the *new paradigm work.* This is a major cognitive shift.

Building Information Modelling (BIM) is an important aspect of this strategy, enabling the exchange of interoperable digital data. This representation includes 3D geometry, 4D phasing (3D space + time), 5D costing (4D + cost), as well as spatial information, geodesic information, and properties of building components and elements.

Conclusions; Emerging Trends, Future Issues and Vision

The construction industry has changed markedly over the last twenty years and this has put an increasing pressure on design teams and design professionals to deliver. The key trends affecting design team performance can be summarized in the following three areas:

Contractors at the Heart of the Design Process: - The establishment of Design-Build procurement and the increasing use of PFI (Private Finance Initiative) has led to earlier contractor involvement. Contractors can now find themselves at the heart of the design process, in a position to influence or control design outcomes. In the worst examples of contractor-led projects the design team is treated as just another member of the supply chain and the inherent importance of good design is often lost by a one dimensional approach to management. Typical construction management methods are not applicable to design and new methods need to be adopted for managing design work.

Increasing Specialism within Design - The complexity of modern materials, systems and solutions require defined specialist knowledge such that designers move from being generalists to specialists. More designers are involved, which is further compounded by the increasing importance of design input from trade contractors. With more parties and more technically complex solutions, even the most experienced Design Manager can fail to ensure that correct information is supplied at the correct time.

Recognition that Design is a Process - The traditional view is that all designs are unique and therefore cannot be planned or managed. This view is no longer valid; design is a process, which if correctly represented can be repeated from one project to the next and can be defined, measured and improved upon. It is now possible to pay design teams in a similar manner to contractors, based on their performance, avoiding exhaustion of fees before design is complete. By defining the process and measuring the design team’s output, the design team can be properly managed and their fee based on performance rather time spent.

Brandon (1999) stated his vision as: A competitive industry working collaboratively for mutual advantage… in order to *reduce conflict, aid communication, seek efficiencies, upgrade the industry and its staff to be comparable with other industries, delivering a product over its full life-cycle which is of high quality, and high value and responsive to time objectives by those commissioning the product.*

In a fast changing design environment, the value of management decisions depends on:

- The quality of information available;
- The ability to access the information effectively.

A more effective and competitive construction industry will thus be achieved.

References

Austin, S., Baldwin, A. and Newton, A. (1994). "Manipulating the Flow of Design Information to Improve the Programming of Building Design." London, Spon, *Construction Management and Economics*, 12 (5) 445-455.

Austin, S.A., Baldwin, A.N., Li, B., Waskett, P., (1998), "Analytical design planning technique (ADePT): programming the building design process", Department of Civil and Building Engineering, Loughborough University, Leicestershire.

Austin, S., Baldwin, A., Hammond, J., Murray, M., Root, D., Thomson, D. and Thorpe, A.(2001), *Design Chains: A handbook for integrated collaborative design*, Thomas Telford, London.

Austin, S.A., Baldwin, A.N., Newton, A.J., (1996), "A data flow model to plan and manage the build design process", *Journal of Engineering Design*, Vol. 7, No. 1, pp 3-17.

Baldwin, A.N., Austin, S.A., Hassan, T.M., Thorpe, A., (1999), "Modelling information flow during the conceptual and schematic stages of building design", *Construction Management and Economics*, Vol. 17, No. 2, pp. 155-167.

Ballard, G. and Howell, G.(1998), Shielding production: Essential step in production control, *Journal of Construction Engineering and Management*, ASCE. Vol. 124, No.1, pp 18-24.

Ballard, G. and Koskela L. (1998). "On the agenda of design management." *Proc. 6th Annual Lean Construction Conference*. Guarujá, Brazil

Brandon P.S. (1999), "Process/Product Development in 2000 Beyond", Berkeley – Stanford Workshop CE & M.

BRE, Building Research Establishment 1995, "Project management: network analysis".

Burati, J.L., Farrington, J.J. and Ledbetter, W.B., 1992, "Causes of quality deviations in design and construction", *Journal of Construction Engineering and Management*, Vol.118, No. 1, pp 34-49.

Business Round Table, 2002, *Teamwork2000 – an experiment in collaborative working*, Business Round Table, Kenley, Surrey, UK.

CIDA, 1995 "Measuring up or muddling through: Best practice in the Australian nonresidential construction industry, Construction Industry Development Agency and Master Builders, Australia, Sydney, Australia, pp 59-63.

Cockshaw, Sir A., 2001, Changing Construction Culture. *Interdisciplinary design in practice*, (eds. R. Spence, S. Macmillan, and P. Kirby), Thomas Telford, London, pp 15-21.

Common, G., Johansen, E., Greenwood, D., 2000, "A Survey of the Take-Up of Lean Concepts among UK Construction Companies", *Proceeding of Conference of the 8th International Conference for the Group for Lean Construction*, Brighton, England.

Cornick, T. (1991). *Quality Management for Building Design*. Rushden, Butterworth, 218 pp.

Cross, N. (1989), *Engineering Design Methods: Strategies for Product Design*, John Wiley & Sons, New York.

Egan, Sir J., 1998, "Rethinking Construction: the report of the construction task force", *Department of the Environment, Transport and the Regions*, London, UK.

Ferguson, I. (1989). *Buildability in Practice*. London, Mitchell. 175 pp.

Ferguson, K.J. and Teicholz, P.M., 1992, "Industrial facility quality perspectives in owner organisations", Technical Report 17, CIFE, Stanford University.

Formoso, C.T., Tzotzopoulos, P., Jobim, M.S.S., Liedtke, R, (1998), "Developing a protocol for managing the design process in the building industry", *Proceedings of the 6th International Group for Lean Construction Conference*, Guaruja, Brazil.

Frankenberger, E. and Badke-Schaub, P., 1998 "Modelling design processes in industry- empirical investigations of design work in practice", *Automation in Construction*, Vol. 7, No. 2-3, pp 139-155.

Freire, J. and Alarcon, L.F. 2000, "Achieving a lean design process" in *Proceeding of the 8th International Group for Lean Construction Conference*, Brighton, England.

Gray, C. & Hughes, W. (2001), *Building Design Management*, Butterworth-Heinemann, UK.

Gray, C., Hughes, W. and Bennett, (1994), *The Successful Management of Design*, Centre for Strategic Studies in Construction, The University of Reading.

Heath, T., Scott, D., Boyland, M., 1994 "A prototype computer based design management tool", *Construction Management and Economics*, Vol. 12, No. 6, pp 543-549.

Hendrikson C.(1998), *"Project Management for Construction",* 1st Edition, Prentice Hall.

Howard R. (1999), "Visions of Some Priorities for Design and Construction Research in Future", Berkeley – Stanford CE & M Workshop.

Howard R. (2000), *"Design Management – Optional Module – Workbook 1",* University of Bath, UK.

Huovila, P.; Koskela, L., and Lautanala, M. (1997). "Fast or Concurrent: The Art of Getting Construction Improved." In Alarcon, L.F. (Ed.) *Lean Construction*, Rotterdam: A.A. Balkema: pp. 143-160.

IAI, International Alliance for Interoperability, 2011, http://buildingsmart.com/, accessed on August 15, 2011

Kagioglou, M. Cooper, R., Aouad, G., Hinks, J., Sexton, M., Sheath, D., (1998a), "*Generic design and construction process protocol final report*", University of Salford, Salford, UK

Kagioglou, M., Cooper, R., Aouad, G., Sexton, M., and Sheath, D. (1998b). "A Generic Guide to the Design and Construction Process Protocol". *Research Report*. The University of Salford, Salford, UK.

Kochan, A., 1991, "Boothroyd / Dewhirst – quantify your designs", *Assembly Automation*, Vol.11, No. 3, pp 12-14.

Koskela, L. (1992). "Application of the New Production philosophy to Construction". *Technical Report No. 72*, Stanford, CIFE, Stanford University.

Koskela, L. (1999), Management of Production in Construction: A Theoretical View, 26-28 July 1999, University of California, Berkeley, CA, USA, Proceedings IGLC-7

Koskela, L., Ballard, G. & Tanhuanpää, V.P. (1997). "Towards lean design management." *Proc. 5th Annual Conf. Intl. Group for Lean Construction*, Gold Coast, Australia, 16-17 July, pp. 1-12.

Koskela, L., Huovila, P. and Leinonen, J. (2002), Design Management in Building Construction: From Theory to Practice, Journal of Construction Research, Vol. 3, No. 1, 1-16 World Scientific Publishing Company)

Lafford, G., Penny, C., O'Hana, S., Scott, N., Tulett, M., Buttfield, A., (1998), *Managing the Design Process in Civil Engineering Design and Build - a guide for Clients, Designers and Contractors, Funders Report CP/59*, Construction Industry Research and Information Association, London.

Latham, M. (1994), Constructing the Team—Final Report of the Government Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry, HMSO Publications, UK.

Lawson, B. (1997). *How Designers Think: the design process demystified*. London, Architectural Press. 216 pp.

Love, P.E.D., Mandal, P., Smith, J., Li, H. 2000, "Modelling the dynamics of design error induced rework in construction", *Construction Management and Economics*, Vol. 18, Pt. 5, pp 567-574.

Machowski F. and Dale, 1995, "The application of quality costing to engineering changes", *International Journal of Materials and Product Technology*, Vol. 10, No. 3, pp 378-388.

Marosszeky, M. and Karim, K., 1997, "Benchmarking – a tool for lean construction", *Proceedings of the 5th International Group for Lean Construction Conference*, Gold Coast, Australia.

Mitropoulos, P. and Tatum, C.B., (2000), "Management-driven integration", *Journal of Management in Engineering*, Vol. 16, Pt. 1, pp 48-58.

Mokhtar, A., Bedard, C., Fazio, P., (2000) "Collaborative planning and scheduling of interrelated design changes", *Journal of Architectural Engineering*, Vol. 6, No. 2, pp 66-75.

Morris, J., Rogerson, J., Jared, G., (1999), "A tool for modelling the briefing and design decision making processes in construction", *School of Industrial and Manufacturing Science*, Cranfield University, Cranfield, UK.

Newton, A. and Hedges, I., (1996), "The improved planning and management of multidisciplinary building design", *CIBSE / ASHRAE Joint National Conference*.

O'Brien, M.J., 1997, "Integration at the limit: construction systems", *International Journal of Construction Information Technology*, Vol. 5 No. 1, pp 89-98.

Ogunlana, S., Lim, J., Saeed, K. (1998), "DESMAN: a dynamic model for managing civil engineering projects", *Computers and Structures*, Vol. 67, No. 5, pp 401 - 419.

Powell, J. A.; Newland, P., (1994), "Informing multimedia: a sensitive interface to data for construction design professionals" *Design Studies*, Vol. 15, No. 3, pp 285.

Prescott, Rt. Hon. J., 1999, Department of Transport and the Regions press release, 19 July.

Pressman, A., 1993, *Architecture 101: a guide to the design studio*, Wiley, New York.

Richardson, G., 1991, *Feedback thought in social science and systems theory*, University of Pennsylvania Press, Philadelphia, USA.

Sheath, D.M., Woolley, H., Cooper, R., Hinks, J. and Aouad, G., 1996, "A process for change – the development of a generic design and construction process protocol for the UK construction industry", *Proceedings of InCIT '96*, Syndey, Australia.

Steele, J., Parker, A., Kirby, P., 2001, Working Together: Short Courses for Design Teams. In *Interdisciplinary design in practice*, (eds. R. Spence, S. Macmillan, and P. Kirby), Thomas Telford, London, pp 140-151.

Sterman, J.D., 1992, "*Systems dynamics modelling for project management*", working paper, Systems Dynamics Group, Sloan School of Management, MIT, Cambridge, MA.

Treasury Task Force, 2000, *How to Achieve Design Quality in PFI Projects*, Technical Note 7, HM Treasury.

Tzorzopoulos P. & Formoso C.T., (1999), "Considerations on Application of Lean Construction Principles to Design Management", Proceedings IGLC – 7, University of California, CA, USA.

Womack, J.P., Jones, D.T., Roos, D., (1990), *The Machine that Changed the World*, Harper Perennial.