CRAFT CONSTRUCTION, MASS CONSTRUCTION, LEAN CONSTRUCTION: LESSONS FROM THE EMPIRE STATE BUILDING

Rebecca Partouche[1], Rafael Sacks[2] and Sven Bertelsen[3]

ABSTRACT

Despite much research and debate on the subject, the definition of lean construction is still under question. Contrary to the linear evolution of production systems from craft to mass and lean, with agile production following as a clearly defined management strategy, construction systems have not developed from craft to industrialized and lean. The focus of industrialized construction is on prefabrication in off-site industrial facilities, and cannot be considered to be the equivalent of mass production in construction. One of the world's most impressive building construction projects, that of the Empire State Building, highlights the existence of another construction system and justifies the introduction of the term 'mass construction'. Lean construction derives in large part from lean production, but in fact lean construction systems are rooted in three construction systems: craft, industrialized and mass construction. These often co-exist in modern construction projects, making their management complex. One of the challenges for application of lean construction is to identify the right methods to cope with an industry that as a whole has not evolved from craft to mass construction, but one that remains mixed between them.

KEY WORDS

agile production, craft construction, flow, industrialized construction, mass construction, production system design, tall buildings

INTRODUCTION

Much has been researched and written in numerous attempts to define lean construction. The paper "What is Lean Construction - 1999?" (Howell 1999) provided a list of procedures that could be expected to be observed in a construction project that one would describe as 'lean'.

Koskela's original treatise on the applicability of flow concepts to construction (Koskela 1992) and his thesis describing the TFV approach (Koskela 2000) provided important foundations for the discussion. Subsequent papers on the nature of flow in construction (Bertelsen et al. 2007) and the structure of the construction industry (Bertelsen and

[1] Graduate Student, Faculty of Civil and Env. Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel, rebeccap@tx.technion.ac.il

[2] Associate Professor, Faculty of Civil and Env. Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel Phone +972-4-8293190, cvsacks@techunix.technion.ac.il

[3] Consulting Engineer, External Lecturer, Danish Technical University, Roennebaervej 10, Apt 108, 2840 Holte, DK Denmark, Phone +45 4542 4705, sven@bertelsen.org

Sacks 2007) are more recent attempts to define theoretical aspects of what has come to be called 'lean construction'. Some have argued that lean construction embodies aspects of agility (Owen et al. 2006), and even that lean construction should have been called agile construction. The term 'leagile' was coined for an innovative housing supply chain (Naim and Barlow 2003). However, Howell's question "What is Lean Construction?" remains incompletely answered.

To better understand what is meant by 'lean construction', we propose examination of the evolution of construction systems, beginning with craft construction, in juxtaposition to the evolution of production systems. A look at the modern history of construction of tall buildings highlights the fact that construction rates apparently peaked around 1930. Fig. shows the average rates of construction, in terms of number of floors and square meters built per year of construction, for a sample of twenty-eight tall buildings built in the period from 1914 to 2007 (CTBUH 2008; Skyscraper 2008). The Empire State Building is represented by the peak point, which shows its record in terms of construction speed. The recent publication of highly detailed records of this project provides a unique opportunity to learn from one of the world's most impressive building projects. Completed in 1931 in New York City with a height of 381 meters, the Empire State was the world's tallest building for more than forty years. Eighty six floors were designed, engineered, erected and ready for tenants in just twenty-one months, a record that has not been passed since. Throughout the project, the design and management team focused on how to facilitate rapid construction and make management efficient.

Study of the Empire State's project production system as a representative of project management practice at a time when the prevailing management culture was that of mass production can help us understand the management concepts and process design that enabled such rapid construction, and more importantly, can aid in our understanding of the parallel evolution of production and construction systems.

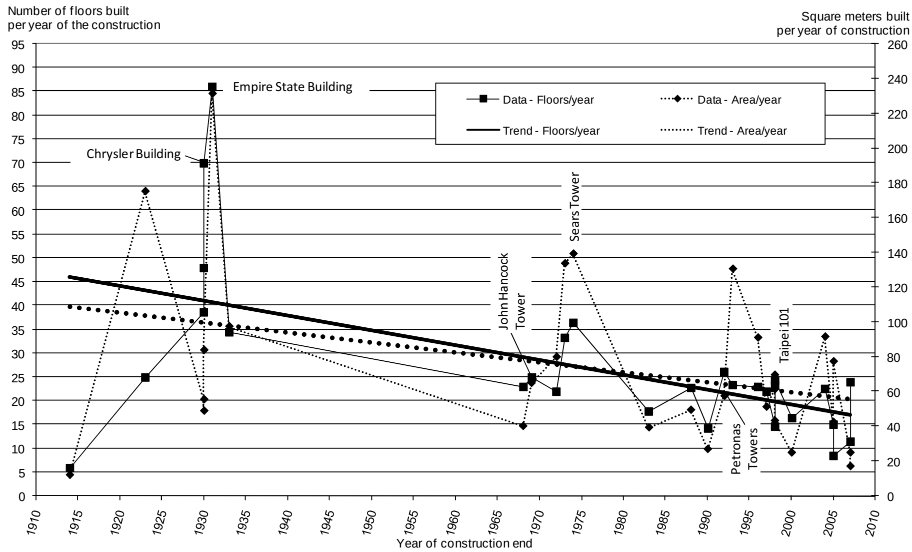

Fig. 1: Construction speed (in floors and area built per year) in tall buildings around the world 1914 – 2007.

PROGRESSION OF PRODUCTION AND CONSTRUCTION SYSTEMS

The progression of production systems is commonly illustrated by the evolution of the car manufacturing industry (Liker 2003; Ohno 1988; Womack et al. 1991). In craft production, parts were unique hand-made products of high quality, and cars were customized to each particular customer. However, damaged parts were hard to replace and productivity was low. At the beginning of the 20th century, Ford and others implemented mass production, in which cars in production flowed continuously along an assembly line (Taylor 1911). Parts were standardized and machines replaced hand-made fabrication methods. However, the ability to customize products was lost. Many of the ills of mass production (waste, over-production, long cycle times, etc.) were redressed with the development of the Toyota Production System (TPS), which has become the model for lean production systems. Where Henry Ford saw efficiency, Taiichi Ohno saw various forms of waste. Lean production emphasizes smooth and small batch flow with little inventory of work-in-process, short cycle-times and the ability to respond to changes in the products a market demands.

Yet another step can be discerned in the development and definition of agile production, in which a company consciously builds a flexible network of suppliers that enable it to reconfigure its production capabilities proactively to meet changes in demand (Preiss 2006; Sanchez and Nagi 2001). Agile is a management strategy more than it is a production system, concerned primarily with the make-up of companies and the relationships between them, and less with actual 'factory physics' (Hopp and Spearman 1996). Preiss (2006) provides an excellent distinction between the four systems, along the two axes of coupled vs. de-coupled and static vs. dynamic systems, as shown in Table 1. De-coupled systems are separated by inventories (of raw materials, interim products or finished goods), while coupled systems have little or no inventory between workstations (using just-in-time and pull flow). The static systems require re-configuration to change from one product to another, while the dynamic systems make the ability to change to meet fluctuating demand – effectiveness – a priority over efficiency. All real systems function within the continuum between the extremes represented by these definitions, since none are completely coupled or completely dynamic.

Table 1: Classification of Production Systems (Preiss 2006).

	Static	**Dynamic**
De-coupled	Mass	Craft
Coupled	Lean	Agile

The construction industry differs significantly from the car industry because of intrinsic physical aspects such as the scale of the final product, the immobility of buildings under construction (as opposed to the mobility of cars along production lines), the higher degree of design variation and exposure of the construction site to external conditions. However, despite these physical differences, the transfer of expertise between industrial sectors suggests that the progression of construction systems can be explained through comparison to production systems in the car industry (Gann 1996).

Originating in the pre-industrial age, craft construction embodies practices which result in custom-built construction according to owners' requirements. Even when a row of similar or identical houses was built, there were variations in each due to the methods deployed. Craft workers developed skills including knowledge of materials and manual dexterity to perform the specific tasks (Gann 2000). The 19th century was a period of rapid changes with the introduction of industrialized techniques of construction. A famous example of the time is Joseph Paxton's Crystal Palace (built between 1849 and 1851) which was assembled from a very large number of modular iron structural and window components. It embodies the departure point of industrialized construction, including standardization, prefabrication and mass-produced components. The realization of industrialized construction was supported by the introduction of new materials and the development of special equipment to transport and erect the prefabricated elements. Between the 1950s and 1970s, prefabrication flourished in construction of social-housing in many countries (Warszawski 1990, Bertelsen 1997).

Industrialized construction focused on producing selected components off-site and failed to meet fragmented and diversified demand. Construction on site remained heavily dependent on crafts for foundation and finishing works, and the mix between inherently incompatible industrialized and craft components was a frequent source of quality failures. Conventional wisdom suggests that the next evolutionary step was lean construction, which applied the lean thinking embodied in the TPS to identify the wastes in construction and propose a new project-oriented management approach (Ballard 2000). The emphasis placed on smooth flow of product in lean production is paralleled by the goal of smooth flow of work in lean construction, where work crews rather than products move. The emphasis on flow extends to consideration of flows of work, crews, information, space, equipment, materials and external conditions (Koskela 2000). Low levels of WIP and careful sizing and placement of other buffers are additional key concepts.

However, there seems to be a gap in this continuum. After all, the importance of smooth product flow and reducing variation (at least in product) were well understood in mass production systems; they were not new in lean production. At the same time, industrialized construction cannot be considered the construction parallel of mass production; rather than changing the practices on site in fundamental ways, it was entirely focused on moving production from sites to factories. Were mass production principles applied on site? Analysis of the Empire State Building suggests that it is a prime example of what we propose to call *mass construction*.

BUILDING THE EMPIRE STATE BUILDING

The Empire State Building set speed records in both design and construction and was completed well within its initial budget. The contracts with the architects were signed in September 1929 and the first structural columns were set in April 1930. Only one year later, the building was fully enclosed, with a height equivalent to 102 stories (80 stories of rental space, 5 floor-observation and the mast mooring equivalent to 17 stories), 200,000 m^2 of rental space, 57,000 tons of structural steel, 48,000 m^3 of concrete with 270,000 m^2 of reinforcement mesh, 10 million bricks and the involvement of more than 3,500 workers on site.

Obviously, many factors contributed to the success of the production system. Design was a collaborative effort performed with full participation of the general contractor. Despite the large scale of the building, the product and process designs were lead by simplicity aimed at providing logical answers to economic and technical problems. This consideration led the project's management to apply the same construction technologies they would have used for a smaller building, adapting only the size; they worked with existing technologies as far as possible in order to avoid the uncertainty of innovative methods. The designers' goal was to minimize variety and complexity; the design used a well known physical structural system (structural steel frame with arched reinforced concrete floors) and exterior metal trim and limestone for the facades.

The construction system had many mass production features, such as the adoption of scientific management with monitored controls (Taylor 1911), the production of high volumes of standardized products with a high production rate, the breaking of processes into small fragments, the mechanization of standardized tasks with high volumes, and the creation of a moving and non-stop assembly line. For example, elements –such as metal spandrels, windows frames, stones – were standardized as much as possible to reduce the time of installation and to enable subdivision of tasks into smaller subassemblies (Willis and Friedman 1998).

Material transportation was also designed as a mass production process: materials were brought to workers in order to reduce the workers' movements on site. They considered the unloading and distributing of materials as an assembly line of standard parts, which had to "*keep moving with a continuous feed of materials to the men*" (Willis and Friedman 1998). Numerous derricks were used for the structure and shafts with mine hoists were used in combination with dumpers that ran on rail tracks within floors to deliver materials. The logistics management team precisely planned the arrival on site of every material. Their challenge was described as *"getting men and materials present when and where they were needed"* (Willis and Friedman 1998).

Another point, prominent in Ford's thinking, was to impose the production rate on the works and to adjust teams to meet the same rate at each workstation. The concept was applied on the Empire State project by the main contractor's control of the construction pace so as to create continuous work flow. All activities were scheduled according to a rhythm set by four TAKT activities, with carefully set time buffers between the four main activity groups to absorb variation.

As expected, the work on site was supported by off-site fabrication (industrialized construction) as far as possible: "*Windows, spandrels, steel mullions and stone were all designed so that they could be duplicated in tremendous quantity and with almost perfect accuracy, then brought to the building and put together"* (Tauranac 1995). The metal spandrels were standardized in only eighteen variations in a total of 5,704 elements. The windows frames were ordered off-the-shelf in order to avoid experimentation and custom manufacturing.

One of the key characteristics of mass production is large batch sizes, which result from optimization driving economies of scale. In office buildings, the product is rental space. The Empire State project produced a very large batch of identical rental spaces, reaching fully 12 % of the total office rental spaces in Manhattan at the time. By the end of the construction of the Empire State Building, at the time of the Great Depression, the vacancy rate of rental office space in New-York City was approximately 16% (Tauranac 1995). Moreover, by the end of 1933 only 25% of the space was rented (i.e. 56 floors remained empty) and the building was not fully occupied until 1950. Large batch-size production had far exceeded demand, an example of the waste of over-production common in mass production.

These features highlight the importance of the influence of Ford's concepts on the conscious design of the production system set in place for the Empire State Building. They lead us to identify it as a *mass construction* system[1].

---

[1] The scope of the analysis of the Empire State Building project in this paper is limited to forming a conceptual view of production and construction systems. Other lessons could be learned, such as design for constructability, logistic systems and construction safety, and will be explored in later papers.

Fig. 2: Construction of the Empire State Building (Willis and Friedman 1998).

THE DEVELOPMENT OF CONSTRUCTION SYSTEMS

Introducing the term mass construction to define practices to create smooth flow of standardized work with minimum variation and the associated logistics for delivery of crews, materials and equipment on a construction site, as distinct from industrialized construction (moving production from site to factory), allows a richer understanding of the development and context of construction systems. It seemingly creates a construction counterpart to the linear craft – mass – lean progression in manufacturing (see Fig 3).

We define mass construction as a building production system characterized by the following features:

4. multiple uniform and repeated spaces or modules
5. work flow planned using TAKT time,
6. industrial supply chain management,
7. monitoring and control of production rates,
8. carefully designed logistic systems to deliver materials,
9. standardized work,
10. minimal variety of parts,
11. careful control of tolerances between parts.
12. Although there is not yet a clear consensus on a definition of lean construction, some key features are (Howell 1999):
13. a clear set of objectives for the delivery process,
14. maximizing performance for the customer at the project level,

15. concurrent design of product and process,
16. application of production control throughout the life of the product from design to delivery.

Table 2 summarizes the key characteristics of the four different construction systems. The main difference between mass and lean construction is the inability of mass construction to cope with variation in the building design, as opposed to lean construction's adaptability for customized buildings and spaces.

Table2: Key characteristics of four different construction systems.

Characteristics	Construction Systems			
	Craft	**Industrialized**	**Mass**	**Lean**
Nature of the building products	Unique components and unique spaces	Uniform components	Uniform components and uniform repeated spaces	Customized spaces
Labor	High-skilled trades	Low skilled but highly specialized	Specialized trades with narrow focus	Multi-skilled teams
Flow System	No consideration of flow	Push flow - discontinuous flow	Continuous flow (stable due to uniformity of products)	Pull flow
Batch sizes	Small batches	Large batches	Large batches	Small batches
Inventories	Small inventories	Large inventories of components	Large inventories of components off-site, large inventories of spaces	Small inventories
Logistics	No logistics system	Off-site materials logistics system	On-site materials logistics system	On-site and off-site logistics system for all the resources

However, production for building construction is performed both off- and on-site, with both industrialized and mass construction. Also, aspects of craft construction persist throughout, co-existing with mass construction. Unlike in other industries such as car production, in construction, old processes are not completely swept away from one system to another; traditional and modern processes co-exist side-by-side (Gann 2000). As a result, it is often difficult to classify construction projects as belonging exclusively to any one construction system. In the Empire State Building, numerous trades remained essentially craft activities with no industrialization, hand-made and executed by a large number of skilled workers, but being performed within the logistic framework of mass construction (examples are bricklaying, tiling, plastering, lathing, setting marble, waterproofing, caulking).

Thus lean construction should therefore be seen as a progression not simply from craft and industrialized construction, but also from mass construction. Fig 4 shows lean construction as derived from the three other classifications (craft, industrialized and mass construction). It inherits concepts from all three, as well as from lean production.

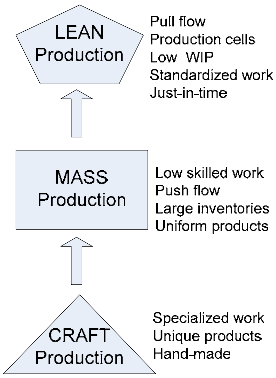

Fig. 3. Evolution of production systems.

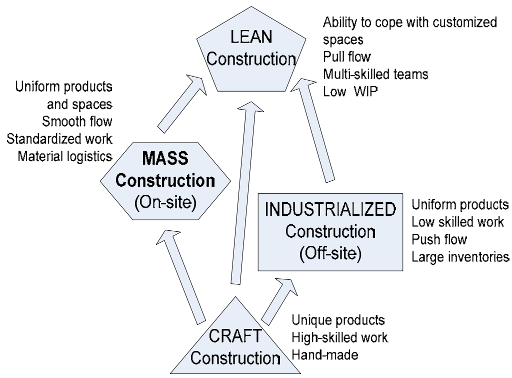

Fig. 4. Evolution of construction systems.

Interestingly, some of the concepts and practices that are typically associated with lean construction can be identified in the Empire State project.

Table analyses the Empire State Building's production system according to Koskela's seven flows. Some of the practices listed that are commonly identified today as lean practices:

- concurrent design of process and product by collaborative teams,
- standardized design of components and work procedures,
- scheduling according to TAKT time1,
- judicious use of time buffers to shield downstream work from activities identified as having high variation,
- pull flow of materials with effective delivery systems,
- de-coupling at offsite staging areas for prefabricated and other materials,
- minimizing of worker travel by provision of all facilities,
- the 'Empire State Club', a forum set up to encourage open dialogue between all project participants.

1 Four main activities set the construction pace of the whole project. These activities were the structural elements: the steel erection, the concrete slab pouring and the façades embodied by the walls and the exterior trim and spandrels. Interestingly these tasks were precisely the activities conceived of and organized as mass production processes.

Table 3: Description of the construction process flows in the Empire State Building

Flow aspect		Description
Design & Information		Collaborative Design Team – immediate flow of design information. Regular release of design information in relatively small batches Standardized and simplified design involved a reduction of information flow needed on site. Creation of the 'Empire State Building Club' to encourage open dialogue among every actor of the project
Previous Work		4 TAKT tasks fit to the structural elements of the building; flexibility of the remaining tasks to follow the pace set by the TAKT tasks
Material	**Bulk Materials**	Pull system to make materials keep moving to workstations Move materials only once Application of "reverse logistics" to remove rubble and packaging Material deliveries to site buffered from deliveries to work locations and weekly inventory of materials Material deliveries outside of the working hours
	Prefabricated Components	No storage of prefabricated elements on site - unloading and setting in place as soon as they arrived Offsite staging: steel elements stored at the wharf and 'pulled' by truck to the site as required
Crew		Staggered working hours of crews to match elevator capacities Food and other facilities provided on floors Guides at elevator relay stations to direct workers
Equipment		11 derricks, 17 hoists, 2 concrete plants, rail tracks and abundant other equipment in a dedicated logistic system Continuous availability during workdays (extensions performed outside working hours)
Space		Storage areas limited Temporary offices on a sidewalk bridge to avoid interference with the activities on site Ample floor areas organized in generic space
External Conditions		By law, work had to be stopped in case of rain, snow, high winds: enclosed building completely before the advent of severe winter weather.

In some respects, many general contracting companies have evolved into agile organizations. The trend to execute work purely through subcontractors, while retaining only project management and head office staff on payroll, enable them to effectively switch between projects of quite different types, such as moving from commercial construction to bridge and highway construction with agility. They typically maintain working relations with numerous and diverse subcontractors. Their challenge therefore is to implement lean construction ideas on a project by project basis. In this sense, in construction, one can consider lean construction to be applicable at the project level (supply chain and project production), while agile concepts are applicable at the strategic level. This demands investment in establishing collaborative lean practices with long-term partners, but at the same time maintaining the flexibility to switch partners to meet the demands of each new project type.

CONCLUSIONS

Consideration of the evolution of production and construction systems, together with study of the Empire State Building's production system, reveals a conceptual gap between *craft construction* and *lean construction* that cannot be filled by *industrialized construction*. Introduction and definition of the term *mass construction* aims to fill the gap and help us understand better the evolution of production systems in the construction industry. In contrast to manufacturing, the evolution in the construction industry is not simply linear. Today's 'traditional' projects are more hybrids of craft and mass construction than lean. Structural work is typically less prone to design change, and so amenable to mass construction methods that include high degrees of mechanization on site (such as automated hydraulic slip-forming systems for reinforced concrete) and prefabrication of components (such as precast façade systems). Finishing works are more frequently changed and tend to slide back into craft construction.

The view of lean construction as a progression from craft, mass and industrialized construction, and drawing some of its concepts from them as well as from lean production, should enable a better understanding of its applicability in relation to specific construction projects. One of the challenges for application of lean construction is to identify the right methods to cope with an industry that has not evolved from craft to mass construction, but one that remains mixed between them.

From the perspective of research toward a theory of production in construction, it is important to recognize the complexity that the mix of craft, industrialized, mass and lean practices in any modern project brings to the problem. It is likely that the underlying principles of flow for each of these are different, in a way analogous to the different physical behaviors exhibited by the same material in different phase states (solid, liquid and gas).

REFERENCES

Ballard, G. (2000). Lean Project Delivery System™. <http://www.leanconstruction.org/>, last accessed September 2004.

Bertelsen, S. (1997) Bellahøj, Ballerup og Brøndby Strand - 25 år der industrialiserede byggeriet. ('Bellahøj, Ballerup og Brøndby Strand - 25 years Industrialising Building'. In Danish). Danish Building Research Institute: pp. 49-59.

Bertelsen, S., Henrich, G., Koskela, L., and Rooke, J. (2007). "Construction Physics." *15th Conference of the International Group for Lean Construction*, C. Pasquire and P. Tzortzopoulous, eds., Michigan State Unviversity, East Lansing, Michigan, 13-26.

Bertelsen, S., and Sacks, R. (2007). "Towards a new Understanding of the Construction Industry and the Nature of its Production." *15th Conference of the International Group for Lean Construction*, C. Pasquire and P. Tzortzopoulous, eds., Michigan State Unviversity, East Lansing, Michigan, 46-56.

CTBUH. (2008). Tall Building Database. <http://www.ctbuh.org/Resources/WorldsTallest/tabid/123/Default.aspx>, last accessed March 2008

Gann. (2000). *Building Innovation: Complex constructs in a changing world*, Thomas Telford Ltd.

Gann, D. M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan." *Construction Management and Economics*, 14(5), 437 - 450.

Hopp, W. J., and Spearman, M. L. (1996). *Factory Physics*, IRWIN, Chicago.

Howell, G. A. (1999). "What Is Lean Construction." *Proceedings IGLC-7*, Berkeley, CA, 1-10.

IGLC. (2007). International Group for Lean Construction. <http://www.iglc.net/>, last accessed July 2007.

Koskela, L. (1992). "Application of the New Production Philosophy to Construction." *Technical Report # 72*, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University.

Koskela, L. (2000). "An exploration towards a production theory and its application to construction," D. Tech, Helsinki University of Technology, Espoo.

Liker, J. E. (2003). *The Toyota Way*, McGraw-Hill, New York.

Naim, M., and Barlow, J. (2003). "An innovative supply chain strategy for customized housing." *Construction Management and Economics*, 21, 593–602.

Ohno, T. (1988). *Toyota production system: beyond large-scale production*, Productivity Press, Cambridge, Mass.

Owen, R., Koskela, L., Henrich, G., and Codinhoto, R. (2006). "Is Agile Project Management Applicable to Construction?" *Understanding and Managing the Construction Process: Theory and Practice, Proceedings of the 14th Conference of the International Group for Lean Construction*, R. Sacks and S. Bertelsen, eds., Catholic University of Chile, School of Engineering, Santiago, Chile, 443-454.

Preiss, K. (2006). "Agility and Leanness." *Proceedings of the International Conference on Agile Manufacturing*, Old Dominion University, Norfolk, VA.

Sanchez, L. M., and Nagi, R. (2001). "A Review of Agile Manufacturing Systems." *International Journal of Production Research*, 39(16), 3561 - 3600.

Skyscraper. (2008). SkyscraperPage.com. <http://skyscraperpage.com/>, last accessed March 2008

Tauranac, J. (1995). *The Empire State Building: The Making of a Landmark*, Scribner, New-York.

Taylor, F. W. (1911). The Principles of Scientific Management. New-York, W. W. Norton & Company, Inc.<http://www.eldritchpress.org/fwt/ti.html/>

Warszawski, A. (1990). *Industrialization and Robotics in Building*, Harper and Row, New York.

Willis, C., and Friedman, D. (1998). *Building the Empire State Building*, W. W. Norton & Company, Inc., New York, London.

Womack, J. P., Jones, D. T., and Roos, D. (1991). *The machine that changed the world*, Harper Business, New York.