# Innovations in Construction

by

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## Abstract

The destruction of urban Europe and Japan during the Second World War, combined with the post war baby boom, created a need for housing for multi-millions of people. The existence of a single large client (the state) and a need for rapid construction combined to provide fertile soil for a boom in the development of industrialized construction techniques. European and Japanese construction firms pioneered many new processes, and today they are still making significant progress in prefabrication and industrialized construction technology. New construction methods and materials, computers and robots are being developed to constantly improve productivity. This thesis aims to bring the reader up to the present situation of the construction industry, by covering past innovations in some detail, as well as referring to what the future of innovation could potentially hold. Barriers to innovation are discussed, followed by three levels of innovative interventions. Organizational interventions, which involve manipulating existing resources to their full potential using human resources, are the first readily available level for immediate utilization. Managerial processes and techniques also play an important role in construction efficiency, innovative management strategies are examined as the second level of intervention. Finally, a thorough description of innovative technologies is carried out, focusing mainly on industrialization, automation and robotics.

Thesis Supervisor: Yehiel Rosenfeld
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***In memory of my father,***

*Apostolos Bachas*

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*"Each player must accept the cards*
*life deals him or her.*

*But once they are in hand,*
*he or she alone must decide*
*how to play the cards*
*in order to win the game."*

# Contents

**Abstract**........................................................................................ 2

**Acknowledgments**........................................................................... 4

**Contents**...........................................................................................6

**List of Figures**..................................................................................9

**List of Tables**..................................................................................10

**Chapter 1 - Introduction to Innovation**........................................... 11

1.1 Innovative Developments in the History of the Construction Process............... 13

1.1.1 Mass Labor...........................................................................14

1.1.2 Tool Development.................................................................... 14

1.1.3 Machine Development.............................................................14

1.1.4 The Advent of Power.................................................................. 15

1.1.5 Advantages in Construction Techniques.................................... 15

1.1.6 Contract Administration............................................................ 15

1.1.7 Advances in Materials................................................................ 16

1.1.8 Designed-In Construction Method............................................... 16

1.2 Future Innovation.............................................................................. 16

1.3 Thesis Layout..................................................................................... 17

**Chapter 2 - Methods of Increasing Productivity**.............................. 19

2.1 Increasing Efficiency of Labor using Quality Circles.................................. 21

2.1.1 The Concept......................................................................... 21

2.1.2 Genesis................................................................................... 21

2.1.3 Technique................................................................................ 22

2.2 Applicability of Quality Circles in Construction....................................... 24

2.3 Managerial Approaches.......... 25

2.3.1 Level Management Models and Standards

of Commitment to Quality.......... 26

2.3.2 Models and Standards of Commitment to Quality.......... 28

2.3.2.1 ISO 9000.......... 28

2.3.2.2 Value Engineering.......... 29

2.3.2.3 Constructability Analysis.......... 31

2.3.2.4 Lean Construction.......... 31

**Chapter 3 - Innovative Technologies.......... 33**

3.1 Obstacles to Industrialization in the Construction Process.......... 36

3.1.1 Uniqueness.......... 36

3.1.2 Fragmentation.......... 36

3.1.3 Dynamic Work Environment.......... 36

3.1.4 Complexity of the Process.......... 37

3.2 Advantages of Industrialization in the Construction Process.......... 37

3.3 Automation.......... 38

3.3.1 Automation in Design.......... 38

3.3.2 Automation of Production.......... 39

3.3.3 Automation of Construction Onsite.......... 40

3.4 Construction Techniques.......... 40

3.5 Future of Industrialization.......... 43

**Chapter 4 – Robotics.......... 45**

4.1 Robot Technology – Application in Construction Industry..........50

4.2 Developed Construction Robots.......... 52

4.2.1 The Assembling Robot........ 53

4.2.2 The Interior General Purpose Robot........ 54

4.2.3 The Horizontal Finishing Robot........ 56

4.2.4 The External Wall finishing Robot........ 57

4.3 Obstacles to the Implementation of Construction Robot........ 58

4.3.1 Technical Problems........ 58

4.3.2 Economical Problems........ 59

4.3.3 Organizational Problems........ 59

4.4 Strategies to Successfully Introduce the Construction Robot........ 60

**Chapter 5 - Setting the Scene........ 61**

5.1 Future Trends........ 66

5.1.1 Conceptual Futuristic Innovations in the Construction Industry........ 67

5.1.2 Initial "Blossomings" of Future Innovations........ 69

**References........ 74**

# List of Figures

Figure 3.1 – Value Engineering Workplan........ 30
Figure 3.2 – Description of T-Up Construction........ 43
Figure 4.1 – Taisei Corporation, Reinforcing Bar Assembly Robot........ 53
Figure 4.2 – Kajima Corporation, Board Placement Robot........ 54
Figure 4.3 – Taisei Corporation, Wall Board Manipulator........ 55
Figure 4.4 – BRONCO (University of Stuttgart), Automated Brick Laying Robot........ 55
Figure 4.5 – TAMIR (Technion Institute of Israel)........ 56
Figure 4.6 – Kajima Corporation, Kote-King, Concrete Floor Finishing Robot........ 56
Figure 4.7 – Troweling Robots........57
Figure 4.8 – Shimizu Corporation, Wall Painting Robot........ 57
Figure 5.1 – Eiffel Tower, Paris........ 62
Figure 5.2 – Home Insurance Company Building, Chicago........ 62
Figure 5.3 – Manhattan Building........63
Figure 5.4 – Ludington Building, Chicago........ 63
Figure 5.5 – United Nations Secretariat Building, New York City........ 63
Figure 5.6 – Construction of a TreviPark........ 70
Figure 5.7 – Construction within Courtyards and Gardens........ 70
Figure 5.8 – Appearance Comparison: Conventional Parking versus TreviPark........ 71
Figure 5.9 – "Fifth Element" Megastructure........ 72
Figure 5.10 – Floating Megastructure........ 72

# List of Tables

Table 1 – Milestones in Construction Processes ........ 13
Table 2 – Main Features of Construction versus Manufacturing Industries ........ 34
Table 3 – Worldwide Sales of Industrial Robots ........ 49
Table 4 – European Sales of Industrial Robots ........ 50
Table 5 – Basic Tasks in Building Construction ........ 52

# Chapter 1 - Introduction to Innovation

Innovation is a key element to improving the performance and competitive nature of any industry sector. It is the key to the City of Tomorrow, introducing new methods and ideas to industry. In the building and construction industry, the design, development, commercialization and effective diffusion of new building products, systems and services are key dynamics, which will shape the industry's long term future.

Though innovation in design and construction is fundamental to achieving our vision for the future character of any city, it is notoriously difficult to achieve for reasons that will be discussed in Chapter 2. This will have to, and can, change; the construction sector knows where the maximum value can be recovered from investment, the community knows where the need is greatest, and so together, quality of life and competitiveness for the industry can be improved. Ways have to be established with which investments in new programs are encouraged.

In construction it is a simple task to point to successes. New materials, fast-track construction and novel design concepts have led to new, exciting structures and a steady improvement in the quality of life for all citizens. The advent of high-speed rail (Magnetic Levitation "Maglev"), for example, has led to new standards of design and comfort, offering competitive trip-time savings to auto and aviation modes – and ideal travel option for the 21st century. On a more mundane level, in the UK, the incorporation of central heating in most homes, has been one of the single most significant improvements to the quality of life for ordinary people over the past few decades.

However, it seems that despite numerous initiatives, when considering any city as a whole, design and construction has had little impact. The reason for this is that whilst it is true that advances have been made in the construction sector, the expectations and demands of the citizens as a whole, have advanced much faster. Contrasting this with advances in the electronics and IT sector, one can immediately see, that as the risk is such lower, homes and offices are saturated with equipment, whose capabilities are far in excess of immediate needs.

Japanese engineering companies have made specific attempts to develop new concepts for urban living, making proposals for building upwards, downwards, or out to sea. In contracting firms such as Kajima, the research and development group provides a central information function for all projects, receiving project experience and propagating new ideas.

Few European and American companies can claim to maintain the continuous commitment to R&D which is the hallmark of many Japanese corporations. A fundamental difficulty for the construction sector in Europe and the U.S. in innovating is the project-based nature of its work. Innovation involves risk. Short-term, project-based assessments of the return on investment for innovation often suppresses the process before any work has been carried out. Trends towards longer term 'partnering' relationships between Clients, Contractors and Consultants will help to overcome this attitude, but it is a cultural change, a paradigm shift, which is required to move the concept of innovation to the top of the project agenda, or even onto the agenda at all.

Innovation therefore, is a process by which engineering and design move forward. In the construction process, innovation occurs when new methods are needed to enable something to be constructed quicker, cheaper or in different conditions. This usually takes place in small steps, however when a completely different method of construction appears, it is possible that innovation happens in one single great leap. Consequently, it is a process, method or technique that has not been used before for a particular construction application. Developments in one project are usually refined and used in the next, or are abandoned as being of no special value.

In this context, it is often said that "Necessity is the mother of intervention". It is true that engineers of all generations have an almost infinite capacity for inventing things, however, due to reasons such as capital intensiveness, fragmentation and degree of legal responsibilities (Rosenfeld, 1994), the government is, in most cases, the only sure vehicle for these engineers to transfer their ideas into a reality. Unfortunately the government is only willing to invest when there is no other option; after an earthquake has devastated infrastructure, a fast way has to be implemented to reconstruct roads and bridges; if many people have been left homeless after a flood, once again, government has to invest in developing a fast way to construct new houses. It can therefore be seen that innovation has to come from people, rather than from organizations.

## 1.1 Innovative Developments in the History of the Construction Process

Great progress has been made in innovative techniques since man first started constructing (Davey-Wilson, 1997). As indicated in Table 1, significant milestones in site construction techniques are most densely concentrated in the 20th century. There are eight categories of innovative developments

| INNOVATIVE METHOD | DATE | INNOVATIVE METHOD | DATE |
|---|---|---|---|
| Use of mass labor<br>Surveying<br>Water Power | BC<br>0 | Prefabrication<br>Centralized Concrete Making<br>Bulk Electricity Supply<br>Grouting Developments<br>Prestressing Concrete<br>Ground Freezing | 1960 |
| Cranes<br>Cofferdams<br>Contracts | 1000 | System Building<br>Slipforming Concrete Structures<br>Reinforced Earth<br>Pressure Balance Tunneling Machines | 1970 |
| Craft Guilds | 1500 | | |
| Horse Grin<br>Treadmill<br>Capstan | 1650 | | |
| Heavy Handling | 1700 | Personal Computer Systems<br>Soil Nailing<br>Designer/Builder Contracts<br>Laser Surveying Equipment<br>Total Station Surveying | 1980 |
| Diving Bell<br>Clay Puddle | 1750 | | |
| Tunneling Shield<br>Compressed Air<br>Steam Power | 1850 | | |
| Hydraulic Power<br>Steam Excavators | 1900 | Global Positioning Systems<br>Novel Financing Methods<br>Computer Monitoring of Machine Performance<br>Observational Methods of Excavation Support<br>Partnering Management On Site | 1990 |
| Tracked Vehicles<br>Internal Combustion Engine<br>Concrete Mixers | 1920 | | |
| Air-placed Concrete<br>Steel Formwork<br>Component Standardization | 1940 | | |

Source: Davey-Wilson, 1997

Table 1 – Milestones in Construction Processes

### 1.1.1 Mass Labor

Ever since the beginning of man, basic needs of shelter, food and reproduction were satisfied by each individual family. The only skills needed for this were to hunt or gather food, and build shelter. Soon after, communities of families began developing, favor exchange became common – one member of the community did something in return for a favor from another member of the community. This allowed the specialist to develop – families that were good at building shelters, would exchange their skills for food from the hunting families. In building, sub-divisions in the labor organizations allowed builders to become specialized in one specific aspect, to which they would become craftsmen. These craftsmen concentrated on one particular part of the construction process, developing into a mason, carpenter or lead worker.

### 1.1.2 Tool Development

The first tools man could find, his hands, were used to manipulate the materials around him, which were used as construction materials. Simple hand tools were developed, following the development of man, first from flint and then from iron to bronze. Primitive infrastructure was thus created, limited always to what a team of men could physically accomplish. Great projects were created just using manpower, however this unfortunately, more often than not, lead to a larger number of casualties – 120,000 in an early attempt to construct the Suez Canal. Obviously the need was evident to develop machines which would aid in the construction process.

### 1.1.3 Machine Development

Greeks were the first to develop early surveying equipment, during the development of the Greek Civilization. It has been noted that a cutting 900m long driven from both ends, in an island in Greece (Samos), proved that surveying technique accurate to about 6m when the cutting met in the middle.

Simple cranes date back to the time of the Roman Empire, and all machines in general were developed through the adoption of levers, pivots, rollers, pulleys and eventually the wheel.

### 1.1.4 The Advent of Power

The perception of what was possible was changed with the coming of power. Compressed air or water could be pumped by early steam engines, which was a huge advance. Similarly, earth moving machines which developed with the introduction of internal combustion engines, greatly increased productivity.

### 1.1.5 Advances in Construction Techniques

The efficiency of construction has been increased due to the introduction of numerous construction techniques. In the construction area alone, one such method recently developed is the "top-down" technique. This technique speeds construction and reduces traffic impacts due to the fact that space is not needed around the excavation for all the material and equipment – it is all stored in the middle of the excavation as each floor is constructed at a time. In the geotechnical area, the introduction of cofferdams, tunneling shields, rock bolts, sprayed concrete, tunnel boring machines, compressed air, site investigations, and geotechnical laboratory equipment, all greatly increase the efficiency of construction.

### 1.1.6 Contract Administration

The promotion and financing method of a project can play a very important role on the way in which a job is tackled. The methodology of construction has recently changed; the contractor has been developed as promoter, designer and builder. Much closer coordination of the designer and builder has become common in recent times, resulting in the process being more efficient as the builder is involved from the beginning (changes can be made ahead of time). Therefore, where fast building is required, as was the case in the 1980s construction boom in the United Kingdom, promoters team-up with designers and builders to form joint development companies. This way, buildings were commissioned in record time using fast track techniques.

### 1.1.7 Advances in Materials

Though early builders used naturally occurring materials, construction was inevitably affected by the development of other materials such as GRP, polystyrene, and FRP composites. Undoubtedly, this leads to economic benefits from savings in man and machine requirements.

### 1.1.8 Designed-In Construction Method

As the name implies, this method involves the incorporation of the temporary works into the construction, thus reducing the cost of the project and introducing savings into the buildability.

## 1.2 Future Innovation

Innovation requires the motivation of people. In the integration of design and construction, experience shows that teams are often brought together from companies that are not used to working together, or even who previously thought of each other as competitors. The management and motivation of the team - and particularly the attitude of senior management - is fundamental to the innovation process. The construction sector has much to learn from other industries, particularly manufacturing, about improving attitudes and reducing costs through innovation. There are many initiatives in this direction; benchmarking 'clubs' are increasingly common, and these are one route to fostering trust and cooperation. Others are needed.

Aside from the process of innovation, there are specific technical fields, which must be addressed if Europe is to maintain its competitiveness in construction technologies. Amongst these, and directly related to the City of Tomorrow, is the issue of underground space. Our cultural heritage is precious to us, and we have a social responsibility to improve the quality of life for all sectors of the community. However, the development and optimal use of underground space remains one of the greatest challenges to the construction sector. Proper consideration of the environmental benefits of underground construction can make it more attractive than surface development (and there are examples where this is starting to take place), but with current techniques the creation of underground space remains expensive. New approaches are urgently needed to reduce the costs of building underground, not necessarily for human occupation, but for storage, goods transportation, and utilities. Underground space should form a clear target for the City of Tomorrow. The benefits of a breakthrough in research in this field would be dramatic across all European cities.

## 1.3 Thesis Layout

The first Chapter attempts to bring the reader through all relevant developments of the past in the construction industry. A thorough historical understanding is required to fully comprehend, and thus be able to anticipate, the pace at which innovations occur.

Chapter 2 introduces the main aim of this thesis, which is to establish methods for improving productivity. As there are three levels of intervention, this chapter discusses the first two, which are the implementation of Quality Circles, and Innovative Managerial Approaches.

The third Chapter examines the innovative technologies available to the construction industry, including processes such as industrialization, automation and a brief introduction to a Japanese construction technique – such as the T-Up construction.

Chapter 4 is a modest summary of the very broad topic of robotics. It includes a description of the roots of robotics, and gives an idea as to robot implementation on a worldwide scale. The application, advantages and obstacles to the introduction of robotics into the construction industry is then explored. Finally, various strategies that could potentially eliminate the reluctance people feel in this field are discussed.

The concluding chapter, is undoubtedly the most interesting - imagination is let loose. A meteoric summary of the development of the construction industry, as well as description of the current situation, is presented. A recent innovation (TreviPark), its implementation and benefits are then introduced.

In concluding, the author undertakes to set the scene for future trends in innovation in the construction industry worldwide, covering issues of general concern.

The author wishes to clarify that the humble task taken upon herself involved the integration and compilation of a number of remarkable articles and books listed in the references. However, additional references are noted, providing for the fact that they were incorporated into the already referenced articles and books, in an attempt to convey the much-deserved credit to all authors involved.

## Chapter 2 - Methods of Increasing Productivity

Regarded as a conservative field, the construction industry is very slow in developing and implementing new technologies and methods. As mentioned in the introduction, there are three main barriers to innovation. Due to the existence of such issues, people are reluctant to innovate when it comes to the construction industry. According to Rosenfeld (1994), relying on Hoffmann (1987), the primary obstacle is the capital intensiveness of the industry. Construction is the sole largest investment made by individuals, corporations and public authorities. As a result, people cling tighter to their pockets, and need to be as sure as reasonably possible that the construction will be risk free. Investing in structures built using new technologies would definitely result in a somewhat uncomfortable feeling. After all, the new innovative method may not live up to expectations; therefore when making investment decisions, stakeholders are very quick to lean towards the well tested designs making use of well tested materials and methods. Potential savings are foregone for the cosy feeling of security, confidence and experience people have with well performing existing products (Burbridge, 1989).

Secondly, the growing number of litigations in the USA and other western societies represent yet another barrier to innovation. This stems from the fact that whenever a new method results in failure of any sort in the construction industry, the designer, engineer or construction manager responsible is faced with the fear of getting sued. The legal responsibilities are immense. However, when was the last time someone was afraid of getting sued for applying approved practices in their construction projects? Never – use of common practice avoids possible criticism and liability claims (Rosenfeld, 1994).

Conforming to Rosenfelds' classification, with reference to Hasegawa (1986), the third feature of the construction industry which represents yet another barrier is its great fragmentation. The imbalance between risk and profit is a factor greatly discouraging inventiveness. When a building appears to serve its expectations, the general public often mistakenly only compliments the architect, however they are in no way hesitant to criticize the engineer if something goes wrong. In a similar manner, the primary beneficiary from a successful innovation is the owner, whereas the primary loser in case of a failure is the engineer. Due to this imbalance, an engineer is disinclined to use new methods – why risk so much to gain so little?

In addition to all the above barriers to innovation, the construction industry is unable to move forward due to declining productivity (Hasegawa, 1987). As Steven G. Allen writes:

> "According to unpublished data compiled by the Bureau of Labor Statistics (BLS), productivity in the construction industry reached a peak in 1968 an except for a brief and small upturn between 1974 and 1976, has been falling ever since. Real output (value added) per hour fell at an annual rate of 2.4% between 1968 and 1978. In contrast, between 1950 and 1968 real output per hour rose at an annual rate of 2.2%. This amounts to a decline in the annual average rate of 4.6 percentage points."

The four main factors affecting productivity are ability, motivation, external factors and job perception. The relationship is a multiplicative one and the general definition of productivity is simply output divided by input (Rosenfeld, 2001). Concentrating on the United States, it is noticeable that the productivity of the construction industry has declined in two stages (Hasegawa, 1987). The first stage was a result of a decrease in capital investment in the mid-1960s and the second stage was due to the decreasing real wages in construction – which used to be among the highest in the national economy.

As the aim of any innovation is to increase productivity and quality of work life, the following chapters will look at various ways this can be done. This will be set out in three different categories, the first of which will focus on increasing the efficiency of labor. The second category, which involves the improvement of capital equipment, consists of innovative technologies. Finally, innovative managerial approaches, describing the various levels of commitment to quality will be examined.

## 2.1 Increasing Efficiency of Labor using Quality Circles

### 2.1.1 The Concept

Quality Circles form an essential part in the Total Quality Control wheel. They are an organizational tool, originating in Japan, that provide a team approach to problem solving and improving productivity (King, 1989). This team, consisting of people from a different level in their respective area of assignment, meets for 1 hour a week to provide a solution to a common problem. Participation is voluntary, but once part of a quality circle, attendance is essential to the process. This scheme is therefore based on the workers personal involvement in the plant prosperity and reputation, and on their motivation to actively advance the aforementioned through quality improvement.

Quality Circles are the least intrusive of all interventions, as it makes use of already existing human resources. People are the greatest of assets of an organization, because through them all other resources are converted into utilities. Quality Circles therefore have emerged as a mechanism to develop and utilize the tremendous potential of people for improvement in product quality and productivity.

### 2.1.2 Genesis

After the Second World War, the Japanese economy was in the doldrums. Seeing this disastrous effect, two American consultants devised the quality control circle concept as one component of a broader integrated quality management campaign to cope with the aforementioned low quality reputation of the Japanese products of those days (Rosenfeld, 2001). During the 1960s, this method had been developed and refined and was put into practice nationwide.

Thus by 1975, Japan was topping the world in quality and productivity. This astonishing and unique achievement in modern history became an eye-opener to the world. Industrialists and politicians from all over the world started visiting Japan to try and learn how they manages to achieve such magical results in such a short span. The answer to this was the painstaking and persevering efforts of the Japanese leaders and workers as well as the development and growth of the philosophy of small working groups. This resulted in the Quality Circle (QC) concept being accepted all over the world as a very effective technique (in many cases merely a "technique" – rather than a genuine mangerial approach) to improve the quality of work life.

### 2.1.3 Technique

The concept of QC is primarily based upon recognition of the value of the worker as a human being. QC concept has three major attributes:

- QC is a form of participation management
- QC is a human resource development technique
- QC is a problem solving technique

The objectives of QC are multifaceted. Primarily, through humanization of work, a change in attitude from "I don't care" to "I care", results in continuous improvement in quality of work life. Self-development, an additional objective, brings out 'hidden' potential of people. Thirdly, the development of team spirit eliminates inter departmental conflicts, emphasizing the difference of individual vs. team. Finally, QCs create a positive working environment, with total involvement of people at all levels resulting in a much higher motivational level.

A QC has an appropriate organizational structure for its effective and efficient performance. Although this may vary form industry to industry and organization to organization, it is useful to have a basic framework as a model.

At the top of the structure is a steering committee that is headed by a senior executive and includes representatives from the top management personnel and human resources people. A coordinator is also required to coordinate and supervise the work of the facilitators. The facilitator in turn, may be a senior supervisory officer. He/she coordinates the work of several QCs through the circle activities. Finally, circle members are the essentials for the program to exist. They are the "lifeblood" of QCs. Circle members may be staff workers, who should attend all meetings as far as possible, offering suggestions and ideas, participating actively in the group process.

The major prerequisite for initiating QCs in any organization is the total understanding of, as well as the complete conviction and faith in the participative philosophy, on the part of the top and senior management. The implementing of QCs involves the following steps:

- expose middle level executives to the concept
- explain the concept to the employees and invite them to volunteer as members of QCs
- nominate senior officers as facilitators
- form a steering committee
- arrange initial training
- arrange meeting for an hour a week for QC to meet
- formally inaugurate QC

Appropriate training for different sections of employees needs to be imparted. Without a proper understanding of the real concept of QC, both the workers and management might look at this philosophy with suspicion. Each group should know before hand the commitments and implications involved as well as the benefit that can be obtained from QCs. Such training comprises of a brief orientation program for the top management, a program for middle level executives, training of facilitators, circle leaders and members.

The operation of QCs involves a set of sequential steps:

1) Problem Identification – identify a number of problems
2) Problem Selection – prioritization, decide which problem to tackle first
3) Problem Analysis – problem is clarified and analyzed by basic problem solving methods
4) Generate Alternative Solutions – identify and evaluate causes and generate number of possible alternative solutions
5) Select the most Appropriate Solution

6) Prepare Plan of Action – to convert solution into reality, includes considerations of "who, what, when, where, why and how" of solving problems
7) Implementation of Solution

The most common quality circle techniques are:

- Brainstorming
- Cause and effect diagrams
- Data collecting and processing techniques
- Pareto diagrams

The tools needed for data analysis include tables, bar charts, histograms, circle graphs, line graphs, scattergrams and control charts

## 2.2 Applicability of Quality Circles in Construction

The discussion is based on a report by Yehiel Rosenfeld, Abraham Warszawski, and Alexander Laufer, in which a counterintuitive hypothesis is presented arguing that construction also features several unique conditions that impart special merit to the QC approach. In the paper, the authors initially attempt to point out why QCs are not suitable for construction. Four reasons are established:

1) Prototypical nature of construction projects - low repetition obviously negates multiplicative effect of method improvement
2) Short term relevancy of problems – apparently the multiple stage of QCs cannot fit into the fast paced environment of construction projects
3) Instability of the workforce – temporary employment and high turnover is common practice in construction
4) Low benefit-cost ratio – questions asked as to whether construction workers can generate valuable suggestions to justify the effort, time and money needed to establish, run and maintain QCs.

However, having presented all the above points against the application and suitability of QCs in the construction industry, it is of great importance and relevance to also examine what gives QCs special merit in construction (Rosenfeld et al., 1986).

Primarily, there is a low initial efficiency in the construction process that creates many opportunities for modifications and improvements on site. This implies that, no matter what, QCs are almost guaranteed to come up with meaningful results. Secondly, although construction projects have a prototypical nature, the actual operations within the project are repetitious. Additionally, the QC process identifies problems early in the process which allows for fast implementation of a solution. This saves in cost and reduces delays and possible problems down the line.

As seen, there are at least as many arguments for as against QCs in the construction industry. After carrying out various experiments in real field settings to establish to what extent and under what conditions QCs may succeed in construction, Rosenfeld et al. illustrate that the QC approach and technique are "highly instrumental in improving both productivity and quality of work life at construction sites". It was also pointed out that against popular belief, the QC concept was easily adopted and implemented by construction managers and foremen as they are not far from team and participative decision making in their daily routine work.

To conclude, having taken all the above into consideration, the introduction of the QC concept into every construction process should seriously be considered as a first degree intervention with an aim to substantially increase productivity using existing resources.

## 2.3 Managerial Approaches

The next least intrusive method for improving productivity makes use of various managerial approaches. According to Rosenfeld (2001), there are four main innovative approaches which can be combined in a synergetic way to achieve optimal production in terms of quality, efficiency and productivity.

A quality product is one that properly fulfills all expectations to the maximum degree, properly serving its intended use. It is not required that the product must be of prime quality as such, however it is obligatory that the customer is not unpleasantly surprised.

How exactly is quality measured? Other than the obvious characteristic of a quality product, that is to say it will perform whatever it has been set to do, reliability is a prime concern. Predictability is an essential feature of a quality product as mentioned previously. A product may still be seen highly if it performs badly, however the malperformance must be predictable. If it is expected, it is assumed that necessary precautions have been taken into account. Accuracy, durability, perfection of details, aesthetics, maintainability and last but definitely not least environmental friendliness, all partake in classifying a product as high quality – it is important to distinguish between the attributes that are more important in each situation.

### 2.3.1 Levels of Commitment to Quality

The planning and controlling of standards for quality are fundamental in both the design and construction phases of a project. Thus, the amplification of the significance of this aspect of a project is completely justified. Quality criteria affect all phases of a project.

Quality engineering involves the application of procedures to ensure that design proceeds according to recommended and mandatory criteria set by professional associations, building code authorities and the environment, while it produces a facility that most economically serves the owner's needs. The elements of quality include the quality characteristics, quality of design, and quality of conformance.

Inspection, which is the first level of commitment to quality, is usually carried out at the end of the process on an accept/reject basis (Rosenfeld, 2001). Consequently, it is significant to make the distinction that the production and the inspection parties are intrinsically in adversarial positions, although they both belong to the same organization.

The second level is quality control. This process consists of three steps, the first of which is the setting of specific standards for construction performance, usually through the plans and specifications. Secondly, variations from the standards are measured, action is then taken to correct or minimize adverse variances and finally improvements in the standards themselves are planned. An appointed inspector from the producers' side is usually appointed to measure the aforementioned variance at the end of major phases during the production process.

Quality assurance, which is the third level of conformance to quality, is generally a broader, all-encompassing term for the application of standards and procedures to ensure that a product or a facility meets or exceeds desired performance criteria. This is mainly carried out by the production department, in order to identify and correct quality related problems during the process. Also included herein is the documentation necessary to verify that all steps in the procedures have been satisfactorily completed. The term transcends both quality engineering and quality control.

Quality management evolves around the idea that quality is number one priority. It is inaugurated and synthesized by senior management, consisting of all parts of the organization, implemented through a systematic and thorough quality assurance process, with the ultimate aim being "zero-defects" (Rosenfeld, 2001).

Finally, Total Quality Management is seen as a way of life aimed at continuous improvement of the organization and continuous personal growth of its individual members. In an article on Total Quality Management, Dexter A. Hansen provides a very comprehensible definition:

Total = Quality involves everyone and all activities in the company
Quality = Conformance to requirements (meeting customer requirements)
Management = Quality can and must be managed
TQM = A process for managing quality; it must be a continuous way of life; a philosophy of perpetual improvement in everything we do.

In this process, "quality" is viewed in the broadest sense (Rosenfeld, 2001), incorporating quality of life, well being and satisfaction of all people involved. The principles involved in TQM are the following:

- Quality can and must be managed.
- Everyone has a customer and is a supplier.
- Processes, not people are the problem.
- Every employee is responsible for quality.
- Problems must be prevented, not just fixed.
- Quality must be measured.
- Quality improvements must be continuous.
- The quality standard is defect free.
- Goals are based on requirements, not negotiated.
- Life cycle costs, not front end costs.
- Management must be involved and lead.
- Plan and organize for quality improvement.

### 2.3.2 Management Models and Standards

#### 2.3.2.1 ISO 9000

The International Organization for Standardization (ISO) is the specialized international agency for standardization, at present comprising the national standards bodies of over 110 countries. The objective of ISO is to promote the development of standardization and related world activities with a view to facilitating international exchange of goods and services and to developing cooperation in the sphere of intellectual, scientific, technological, and economic activity.

The ISO 9000 Series is a set of individual, but related, international standards on quality management and quality assurance. They are generic, not specific to any particular product. They can be used by manufacturing and service industries alike. These standards were developed with the goal of effectively documenting the quality system elements to be implemented in order to maintain an efficient quality system in your company. The ISO 9000 series standards do not themselves specify the technology to be used for implementing the quality system elements.

The objective of an ISO 9000 quality system is to ensure that the facility's output - hardware, software, processed materials, and services - conforms to specified requirements. "Specified requirements" is the term the Standard uses to represent the customer's expectations, both stated and unstated. The basic principle is to "Say what you do; then do what you said".

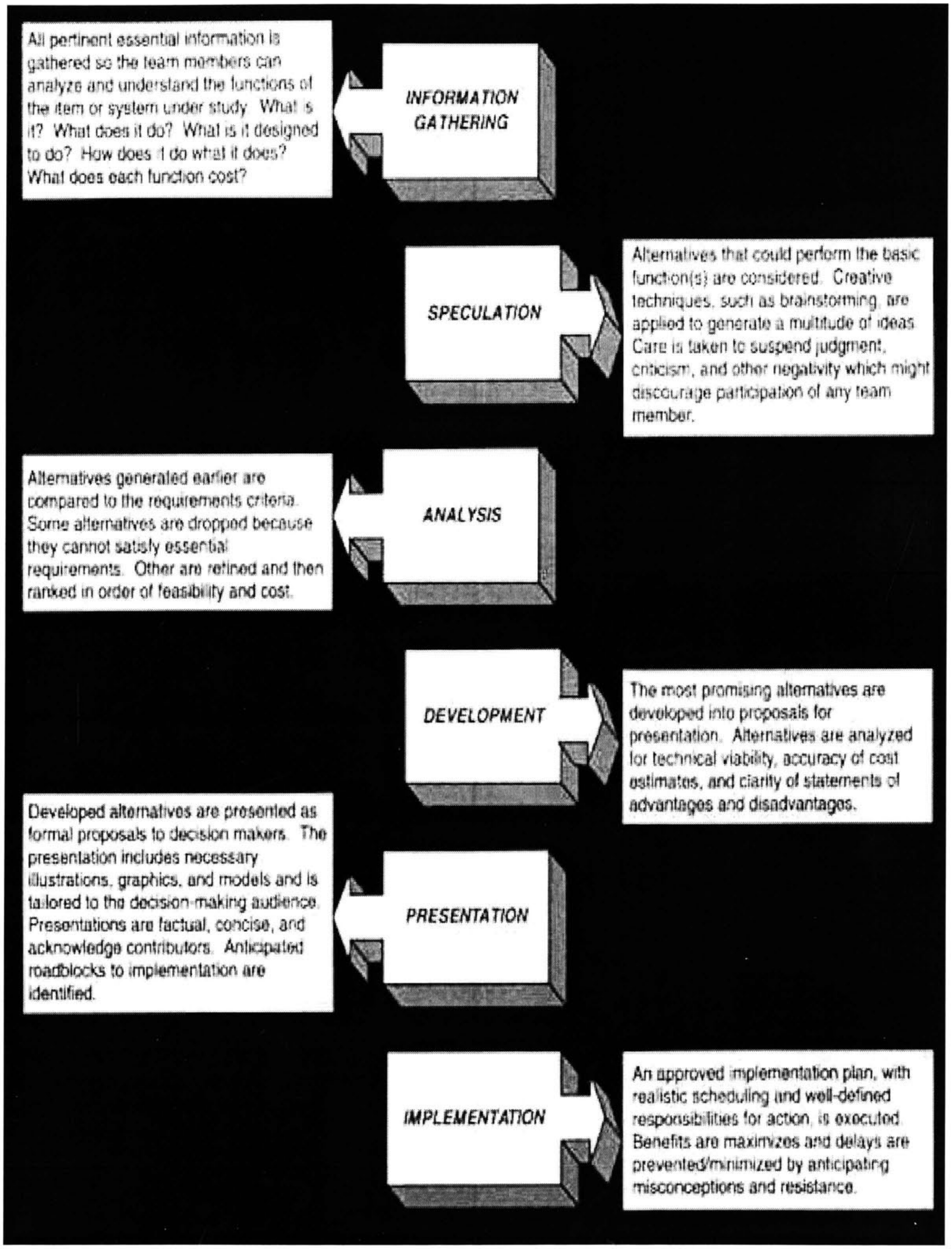
Implementation of an ISO 9000 quality system brings great benefits to the organization. A few of the many key benefits of ISO 9000 registration are: strengthened customer confidence, access to markets, reduced operating costs, competitive advantage and reduced number of customer audits.

#### 2.3.2.2 Value Engineering

Value Engineering (Synonymous with the terms value management and value analysis) is a professionally applied, function-oriented, systematic team approach used to analyze and improve value in a product, facility design, system or service. It is a powerful methodology for solving problems and/or reducing costs while improving performance. By enhancing value characteristics, value engineering increases customer satisfaction and adds value to ones investment. Other than to construction, value engineering can be applied to any business or economic sector, including industry and government.

Value engineering uses a unique, systematic methodology to analyze the functions of items and systems so that required functions are achieved at the lowest possible life-cycle cost. It attempts to identify and eliminate the components that do not contribute to value, aiming to achieve the same value/result more efficiently. An alternative objective is to achieve a higher value with the existing components.

Figure 3.1 gives a thorough explanation as to the process behind value engineering.



All pertinent essential information is gathered so the team members can analyze and understand the functions of the item or system under study. What is it? What does it do? What is it designed to do? How does it do what it does? What does each function cost?

Alternatives that could perform the basic function(s) are considered. Creative techniques, such as brainstorming, are applied to generate a multitude of ideas. Care is taken to suspend judgment, criticism, and other negativity which might discourage participation of any team member.

Alternatives generated earlier are compared to the requirements criteria. Some alternatives are dropped because they cannot satisfy essential requirements. Other are refined and then ranked in order of feasibility and cost.

The most promising alternatives are developed into proposals for presentation. Alternatives are analyzed for technical viability, accuracy of cost estimates, and clarity of statements of advantages and disadvantages.

Developed alternatives are presented as formal proposals to decision makers. The presentation includes necessary illustrations, graphics, and models and is tailored to the decision-making audience. Presentations are factual, concise, and acknowledge contributors. Anticipated roadblocks to implementation are identified.

An approved implementation plan, with realistic scheduling and well-defined responsibilities for action, is executed. Benefits are maximizes and delays are prevented/minimized by anticipating misconceptions and resistance.

Source: Department of Defense, 1986

Figure 3.1 – Value Engineering Workplan

### 2.3.2.3 Constructability Analysis

This approach aims to identify potential problems in the construction phase, prior to actual construction, by evaluating proposed building designs and details for ease of construction. The best people suited to carry out this evaluation are retired project managers, who have all the necessary experience, with different types of designs, and "wisdom" needed to determine whether something can be reasonably built or not.

Thus potential problems regarding material compatibility, sequencing conflict, access, long term performance, maintenance frequency, eventual replacement, and many other issues can be anticipated and foreseen prior to construction, so that appropriate steps can be taken to either avoid the conflict or adequately coordinate the construction sequencing. An extention of the constructability concept is preassurance that the different designs conform to all relevant laws, building codes, municipal by-laws, etc. Substantial money can be saved on a project due to increased construction efficiency, fewer delay, less re-work, reduced maintenance costs, and overall improved performance of the facility. And the cost of making the necessary changes ahead of time is minimal.

### 2.3.2.4 Lean Construction

Lean production is a philosophy of production management often contrasted to mass production and craft production. While the construction industry has adopted elaborate techniques for project and contract management, the management of production has been neglected; construction remains essentially a craft form of production. However, the achievements of manufacturing have triggered the development of new thinking and techniques for managing work in the design and construction of capital facilities. Application of this new approach has produced significant improvements on complex, uncertain and quick projects through better management of the project delivery process and improving the reliability of workflow.

The objective of Lean Construction is to better meet customer demands and dramatically improve the construction process. Lean Construction principles include:

- Elimination of waste

  Taiichi Ohno (1988), who articulated the lean production philosophy and implemented it in Toyota's production system, classified sources of waste as follows (8 added by Womack and Jones, 1996):

  1. Defects in products;
  2. Overproduction of goods not needed;
  3. Inventories of goods awaiting further processing or consumption;
  4. Unnecessary processing;
  5. Unnecessary movement of people;
  6. Unnecessary transport of goods;
  7. Waiting by employees for process equipment to finish its work or for an upstream activity to complete;
  8. Design of goods and services that fail to meet user's needs.
- Precisely specify value from the perspective of the ultimate customer
- Identify the process that delivers what the customer values, eliminate non-value-adding activities
- Make the remaining activities flow without interruption by managing the interfaces
- Don't make anything until it is needed and then make it quickly (customer pull)
- Pursue perfection by continuous improvement
- Reduce overall process cycle time
- Synchronize and physically align all steps in the production process ("Just-in-time" process – tries to eliminate multiple handling).

It is important to note that all the aforementioned approaches can be combined in a synergetic way to obtain optimal results.

# Chapter 3 - Innovative Technologies

The next step in increasing productivity is replacing manual labor by implementing industrialization and automation into the building process. The industrialization process will be viewed as an investment in equipment, plant and technology, the essence of which is to increase output, decrease human labor and improve quality (Warszawski, 1999).

The motivation behind decreasing manual labor stems from the fact that even those people with limited choices, as far as their career is concerned, prefer not to endure the hardships of construction. This hard labor needs to be reduced, not only due to individual preferences but also due to the shortage of labor, which is a direct result of this. In addition, improvement of quality does not necessarily require that the product be superior, simply that a minimum quality is guaranteed. Machines can be relied on to reproduce the desired quality almost 100% of the time.

In order to fully understand the role industrialization plays in productivity improvement, it is important to establish the prerequisite features. First and foremost, a general characteristic of successful industrialization is mass production. This implies that large volumes must be produced in order to justify the investment in the equipment and facilities associated with this process. The underlying logic is that this large volume will prevent unduly rises in the price of product units by distributing the fixed investment charge.

A second very important characteristic is the concentration of production linked to the industrialization process. It is here that the economies of scale are used, as the expense of using the equipment and facilities is only justified with production performed at a single location. It is from this location that the goods are then distributed.

Most elements in the industrialization process are standardized, fitting into each other perfectly. This eliminates the need for reinvention every time a new product is developed. If the output is standardized, the production process, machinery and workers can be used in the most efficient manner possible. This is a totally different notion, examples of which are car tires - a few dozen fit all sizes, batteries, films and screws which are greatly standardized.

Similarly, training of the production labor can be focused on carrying out particular tasks in order to complete the final product. This specialization allows workers to perform the particular task they are involved with at a much higher productivity, as they are much more competent at that particular task than anyone else in the task force.

Finally, for the success of the industrialization process, a sophisticated organization capable of ensuring efficient workflow, and a high degree of coordination are both required.

There are many differences between the typical manufacturing process and the construction process. These differences have been the main reason why the implementation of industrialization in building has taken place at such a slow rate.

| Manufacturing | *Construction* |
|---|---|
| All the work performed at one permanent location | Work dispersed among many temporary locations |
| Short to medium service life of a typical product | Long service life of a particular product |
| High degree of repetition and standardization | Small extent of standardization; each project has distinctive features |
| Small number of simplified tasks necessary to produce a typical product | Large number of tasks requiring a high degree of manual skills necessary to complete a typical construction project |
| All tasks performed at static workstations | Each task performed over large work area with workers moving from one place to another |
| Workplace carefully adjusted to human needs | Rugged and harsh work environment |
| Comparatively stable workforce | High turnovers of workforce |
| Unified decision-making authority for design, production, and marketing | Authority divided among sponsors, designers, local government, contractor, and subcontractors |

Source: Warszawski, 1999

Table 2: Main features of Construction versus Manufacturing Industries

Prior to discussing the obstacles to industrialization in construction, it is essential to understand in what ways, if any, industrialization would compliment the building process. The main principle of industrialization in construction is to carry out as much of the production off-site as possible. The controlled environment would allow for much more efficient production. In addition, where possible, it is preferable that small components be avoided. Sealing of joints, connection formation, welding etc are all potential failure locations, therefore using large components greatly increases the efficiency of erection. Once a crane capable of lifting 8 tons is already on site, not using it to its full capacity would be a waste of time and money. Therefore, using large components and/or complete assemblies where applicable is greatly desired.

One aspect that needs to be addressed as far as housing is concerned is that people generally tend to be individualistic. This implies that, whereas for example with batteries there is no concern, if too many housing units look the same their value will be substantially reduced. Variations must thus be made possible with a limited number of component types - often sufficient to provide differences in the exterior finishing surface, by altering the texture, paint color, keeping the interfaces and periphery of the structures standardized.

The product of the construction industry is very durable – unless collapse is caused by a natural disaster. During the one hundred-year lifespan, the interior design will require some form of change. If construction is too rigid, the structure will be inferior, therefore flexibility must also be designed into the industrialization process. Flexibility must also provide for the desired intra-industry modular coordination (Rosenfeld, 2001). It is required that units produced from different suppliers/manufacturers are compatible with each other. This way it is easy to mix and match different parts from different producers making the whole process a lot more efficient and economical.

## 3.1 Obstacles to Industrialization in the Construction Process

### 3.1.1 Uniqueness

First and foremost, the main obstacle to the introduction of the concept of mass production to the construction process is the distinctive nature of each project. This uniqueness results from the different intended use of each structure, from different surroundings in which the building is erected, and from different perceptions of designers of an optimal solution for a particular combination of a user and an environment. The aim of every sponsor, designer and contractor is to achieve a balance between the benefits of standardization and the costs associated, such as higher monotony, lower satisfaction of an industrial user and even a somewhat lesser effective functionality. Standardization is advocated in the developed countries, so long as quality of a particular solution is not threatened in anyway. It is therefore still a great challenge to allow for a maximum design freedom while simultaneously standardizing requirements.

### 3.1.2 Fragmentation

Even the largest construction firm in the industry controls less than 1% of the market. Rapid return on investment is required resulting in minimal funding allocated to research and the acquirement of heavy technology. Future projects can never be guaranteed, therefore addressing worst case scenario, firms are reluctant to invest in the equipment needed for a successful industrialization process. Alliance has to be established between contractors, developers and owners in order to fully justify investment in advanced technologies.

### 3.1.3 Dynamic Work Environment

The construction process is very dependent on external unexpected and unstructured factors, such as cost overruns and political changes. Aside from the physical hardship of the construction work, the need to move from one location to an other all the time, are inherent features of the onsite conventional construction process.

Therefore, it is somewhat difficult for industrialization to ensure the smooth flow required for the successful just-in-time process. The trick is to develop the ability to determine when the external conditions likely to exist will allow for the adoption of the new technologies needed for industrialization.

### 3.1.4 Complexity of the Process

Building is a big coordination of some 30 to 40 different skilled trades. As there are so many different players there is inherent difficulty to control all the interfaces. In each building there are 4-5 skeleton activities followed by HVAC, elevators, locksmiths, plasterers, which all need to be sequenced in a manner that cannot tolerate miscommunication. If one group breaks the sequence, the whole process is no longer balanced, and subsequently every stoppage halts the entire process.

A major problem facing industrialization is the fact that construction has always been somewhat tailor-made. Very frequently the precise use is unknown at the design and fabrication stage, therefore many of the parts cannot be preproduced/prefabricated in a factory in advance. In addition, the existing poor culture within the construction industry, resulting from the fact that the extent of most peoples vision is to the end of the specific project they are working on, is a serious obstacle that needs to be worked with.

High initial investments, fixed operational costs, sensitivity to market fluctuations, dependency on good management and the limited flexibility all are limitations of industrialization in construction.

## 3.2 Advantages of Industrialization in the Construction Process

The aforementioned benefits are:

1) Less dependency on professional skilled labor – up to 40-50% of the input in conventional construction (Warszawski, 1999)

2) Shorter duration of construction – when the market is booming, industrialization allows for contractors/developers to take advantage of that small window of opportunity and role one project over the other
3) Higher quality – as the units are produced in more controlled environments where materials and production tools can carefully be chosen, the product is usually superior, more often than not fulfilling its promises – living up to expectations
4) Specialization – in a market with shortage of labor, characteristic of most western societies, industrialization seems to provide a good solution as it requires less training, and provides much "cleaner" job opportunities
5) Benefits of mass production which include the more efficient utilization of equipment, plant and material

## 3.3 Automation

Automation in building encompasses all autonomous, preprogrammed activities performed by centrally computer driven machines.

Industrialization in the building process can only be fully assessed by considering the impact of computers on the design, production and assembling onsite of prefabricated elements. Automation seems to be a natural and essential extension of the industrialization process, if the provision of individual solutions to each customer is to be feasible.

Mechanization and automation aim to save manual labor, eliminate difficult, dirty, dangerous and dull work and improve quality.

### 3.3.1 Automation in Design

Once fabrication of building components has started, it is difficult to make changes to the design. This means that the design must be at an advanced stage before construction starts. Computers have helped speed up design considerably in recent years, and can allow designers to thoroughly analyze the building for different purposes before construction starts. When they were first adopted, Computer Aided Design (CAD) packages were simply used to replace tasks normally done by hand, such as drawing, and were not a cost-effective investment. Now, CAD packages can be used for many tasks, ranging from analyzing buildings for heat loss to generating 3-D interior mock-ups. As computer technology and software improve, building designers will be able to do more advanced design work before construction starts.

Prefabricated building components must fit together properly at the site. Some building systems require precise positioning of structural components (e.g., for piping connections). When prefabricated materials and components are manufactured with varying degrees of dimensional accuracy, it can cause problems. For example, a window opening in a prefabricated panel that is too large can create an even larger headache for the window installers. The adoption of Computer Aided Design and Computer Aided Manufacture (CAD/CAM) techniques has helped overcome these shortcomings. Computer controlled cutting and joining tools ensure good dimensional control, and are widely used in the Japanese and Scandinavian prefabrication industries. In Japan, most prefabricated houses begin with 3-D steel structures, although timber use is growing.

Completely finished prefabricated kitchen and bathroom modules (often from different companies than the main house builder) are added at a later stage. Computers play a large part in providing the dimensional accuracy needed in these "pop in" modules.

### 3.3.2 Automation of Production

Various production activities can be automatically controlled using the information received from the design stage. Such activities include preparation of reinforcement and its placement in the molds, mixing and placement of concrete.

### 3.3.3 Automation of Construction Onsite

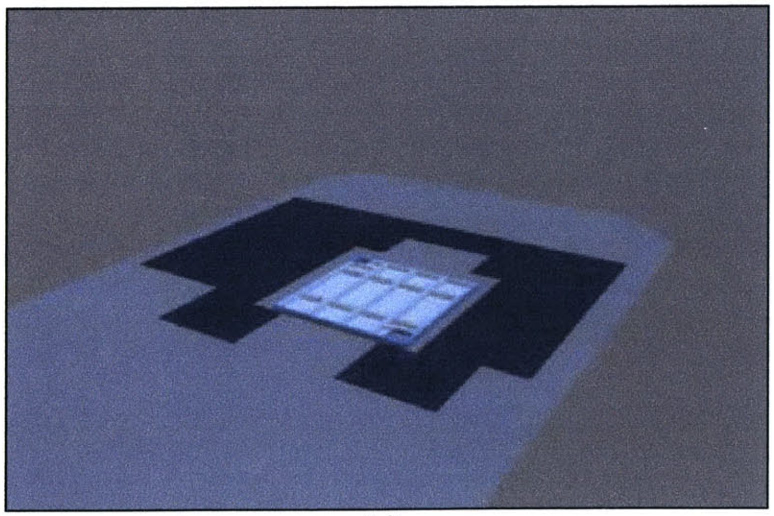
The Japanese and Europeans are also pursuing the development of robots for construction applications (Chapter 4). Robots are faster and more precise than humans, ideal for dangerous jobs, and they don't get sick or go on strike. Robots are most suited for an industrialized construction setting, where prefabrication can be broken down into standard repetitive tasks that can be controlled by computer. Robots can cut and shape, position and connect members to form structural frames with amazing dimensional consistency. There are robots that will paint, trowel concrete, shotcrete, handle materials, and inspect finished prefabricated components for flaws.

Robots are also being developed for site assembly of prefabricated components. Research is being done in England to reduce the complexity and variations of construction joints, so that robots can be used to join panels. The Japanese are developing robotized tools for the building site, and installing rails on prefabricated panels to serve as guides for robots.

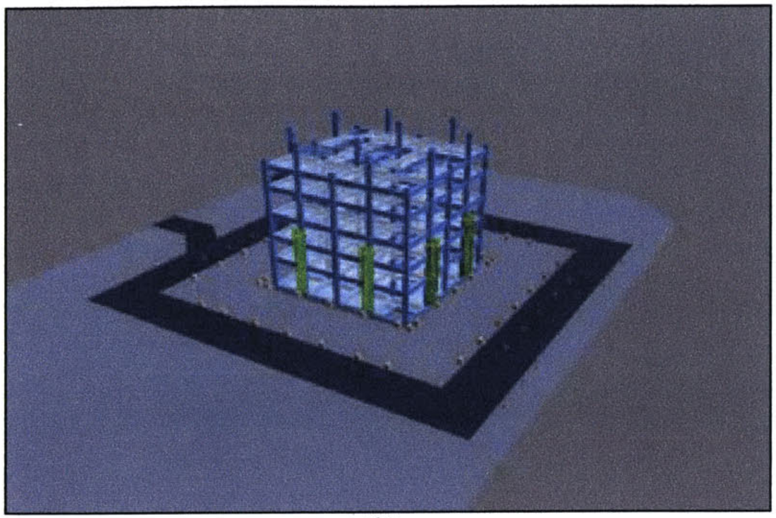
## 3.4 Construction Techniques

New building systems and construction methods are also appearing in the move toward prefabrication. Many innovations depend not on developments in materials science or computers, but on imaginative usage of existing construction technologies and attention to design. Architectural precast panels are now being used, with only small modifications, as load bearing walls by some builders in the United States. The structural use of these panels requires close and early collaboration between the architect and engineer because of additional design complexities such as floor to wall connections and shear reinforcement. Buildings can be designed without a structural core, however, thus providing the architect with more flexibility for floor plans, and can be built for less money than conventional structures. Computer Aided Design packages can simplify structural analysis and facilitate design communications between the architectural and engineering teams.

The Taisei Corporation of Japan has developed the T-Up system, a high rise construction technique ideally suited to erection of prefabricated structures. Once the structural core of a building is completed a "hat" truss structure is assembled and mounted, where it will eventually become the top floor. Travelling cranes are attached on the underside of the "hat" and used to handle and assemble prefabricated floor slabs, beams, girders, and walls. The main advantage is that the "hat" provides shelter from adverse weather conditions, thereby preventing delays and improving working conditions and construction quality. Also, all the equipment may be stored in the working area, thus facilitating construction in heavily congested areas. The lower floors may also be occupied much before completion of the whole structure. After the foundation work (Fig. 3.1(a)) is completed, the structure is built from the central core (Fig. 3.1(b)). Work on the lower floors proceeds in tandem with the work at the core (Fig. 3.1(c)). At first, the top part of the building is used as a work space. The top then rises along the core and protects against wind and rain. The structural spaces on the lower floors are then constructed using machine tools at the top (Fig. 3.1(d)). Finally, the construction of the building proceeds as the top is raised along the core (Fig. 3.1(e)). To disassemble, the hat is jacked down as it was jacked up, and all the equipment is lowered using cranes. The final crane is disassembled itself and is lowered using a small crane it had previously raised to the top. The pictures below provide a thorough description of this newly developed construction procedure.



(a)



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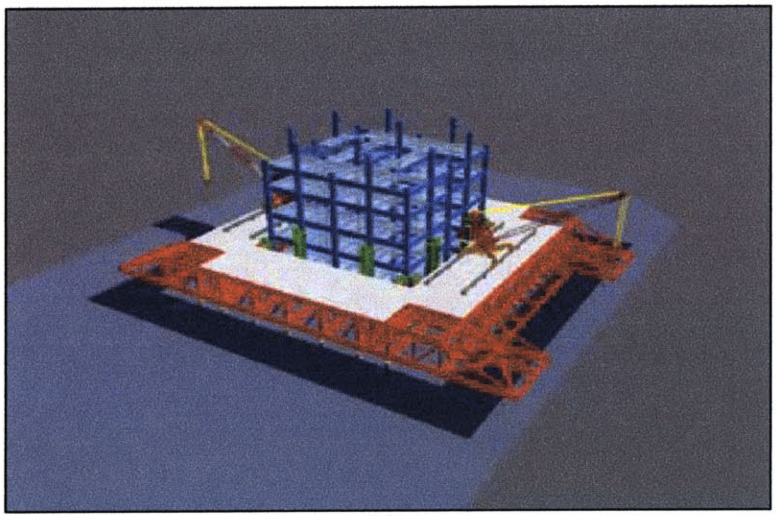

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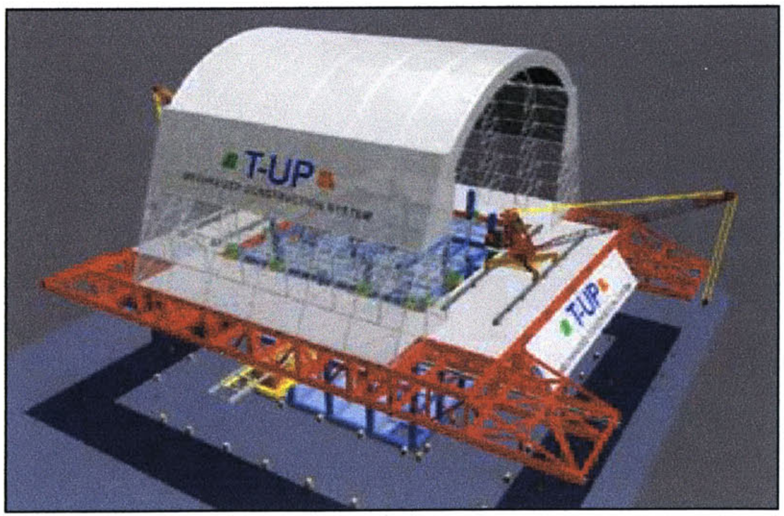

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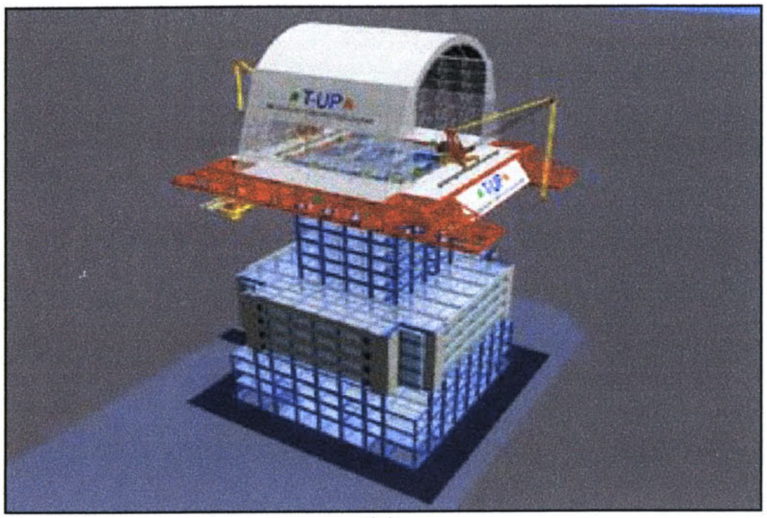


(e)

Figure 3.1 – Description of T-Up Construction

The attachment of concrete reinforcement to structural members before delivery to the site is another time saving innovation. Self-forming steel members are used to construct composite steel concrete structures. A sandwich panel system developed in Austria and used in the U.S. features a welded wire fabric surrounding a foam insulation core. These lightweight panels are assembled to form the outer shell of a house and then shotcreted to obtain an exterior concrete finish.

## 3.5 Future of Industrialization

A number of social factors are also pushing the construction industry toward industrialization of the construction process. The demand for high quality buildings is growing around the world. As they become more educated about energy conservation, lighting, indoor air quality, and other health and comfort related issues, consumers (homebuyers and commercial property owners) increasingly want their buildings to be built to the highest standards. Prefabrication of building components using mechanized, computer controlled tools is one way to consistently achieve high quality. Almost all building materials will be manufactured industrially in the near future, and it is natural to expect more and more assembly of these materials in a controlled environment away from the building site.

Continued growth in communications technologies, consumer electronics, and other creature comfort systems will make building construction more complex. Computer controlled heating and ventilation and multi room access to entertainment and communications are some of the features that will be incorporated in future "smart" houses and buildings. Assembling and installing these technologically advanced systems in an exposed, site built structure will not please the owner.

The construction labor force is aging and shrinking as progressively fewer young people enter the industry. If demand for labor remains the same and the supply decreases, costs will increase. This pressure will lead builders to industrialized construction, which requires fewer specialized trades and people.

Industrially produced buildings have come a long way from the repetitive boxes most people associate with the word "prefabrication". The move to industrial construction is inevitable, and designers and builders should pay attention to its opportunities now.

# Chapter 4 - Robotics

Robotics, as a topic, is very broad. Even when narrowed down to the category of "Industrial Robotics", no two sources will give the same definition of the term. In Japan, for example, any mechanical device that operates in a factory and performs a single, simple task repetitively is considered to be a robot, whereas in America, such devices are considered "automation systems". Although automation systems have been around in factories for several decades, robotics is a fairly young topic in the industrial field.

In America, an automation system, or device, is a mechanical component in a factory that fully or partially replaces an employee that performed a simple, menial task several hundred times per day. Automation systems have been utilized by industrial society since the early twentieth century. They may be complex devices, and they may be controlled by software, but they are physically and electronically designed to do a specific task, and if the industry must make drastic changes to a product, or if a new product is to arrive on the production line, it is likely that most automated machines on the line will have to be replaced. Automation systems are not, however, to be mistaken for robots. Robots are a newer addition to industry beginning in the 1950's.

In the 1973 edition of the Oxford English Dictionary, the entry for "robot" reads as follows:

> Robot (ro-bot) 1923 (Czech, f. _robota_ compulsory service) One of the mechanical men and women in the play R.U.R. (Rossum's Universal Robots) by Karel Capek; hence a living being that acts automatically (without volition). B. A machine devised to function in place of a living agent; one which acts automatically or with minimum of external impulse.

Capek's popular play concerns an industry in which human-like servants are artificially created out of biological material in order to serve the human race in the factories and in the military forces. He called these manufactured workers "robots", from the Czech word _robota_, meaning obligatory work or servitude.

The following definitions have since been provided by ISO concerning robots and automation:

> "Manipulating industrial robot is an automatically controlled, reprogrammable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications"

> "Manipulator is a machine, the mechanism of which usually consists of a series of segments jointed or sliding relative to one another, for the purpose of grasping and/or moving objects (pieces or tools) usually in several degrees of freedom"

A robot is a software-controlled mechanical device that also replaces, or partially replaces a worker in a factory, but, although not nearly as versatile or adaptable as a human, it is much more flexible and universal than its predecessor: the automated machine. A robot can be manipulated to adapt to changes in environment, product design, or to handle an entirely new product, simply by some reprogramming, or electronic alterations on the part of a computer engineer. In the very beginning stages of the development of industrial "robots" - when the word was first introduced into the English language - some people had visions of human - shaped mechanical "creatures". However, the inventor and designers of robots knew then as they know now that robots need not resemble humans to perform the repetitive, tedious tasks that are required in a factory. Thus for example, it was perceived that senses such as taste and smell would not even need to be considered in the design of an industrial robot. As a result of these considerations, most early robots (as well as many robots of today) resemble a single human arm with a relatively unrestricted range of motion, and a clamp, or "hand" for grasping. They were quite versatile in that they could be reprogrammed to grasp different objects, to move in different directions, to grasp with different strengths, etc.

The roots of their development lie in the effort to automate some or all of the operations required on the factory floor (Andrew McGill, 1998). This effort began in the 18th century in the textile industry, when some looms were designed to perform under the control of punched paper tapes. With the burgeoning of the Industrial Revolution, more factories sought to bring a greater degree of automation to the repeated processes of the assembly line. True robots did not become possible, however, until the invention of the computer in the 1940s and the progressive miniaturization of computer parts. One of the first true robots was an experimental model called SHAKEY, designed by researchers at the Stanford Research Institute in the late 1960s. It was capable of arranging blocks into stacks through the use of a television camera as a visual sensor, processing this information in a small computer. Thereafter engineers tried to adapt robotlike devices to useful tasks. The early-1970s mirrored the introduction of industrial robots into the automotive industry which was experiencing labor shortage due to the rapid increasing exports (Hasegawa, 1987). In the mid-1970s, General Motors financed a development program in which Massachusetts Institute of Technology researcher Victor Scheinman expanded upon a motor-driven arm he had invented to produce a so-called programmable universal manipulator for assembly, or PUMA. The PUMAs that resulted mark the beginning of the age of robots.

Below is a timeline for the development of robots (source: Rover Ranch):

~270BC an ancient Greek engineer named Ctesibus made organs and water clocks with movable figures.

1818 - Mary Shelley wrote "Frankenstein" which was about a frightening artificial lifeform created by Dr. Frankenstein.

1921 - The term "robot" was first used in a play called "R.U.R." or "Rossum's Universal Robots" by the Czech writer Karel Capek. The plot was simple: man makes robot then robot kills man!

1941 - Science fiction writer Isaac Asimov first used the word "robotics" to describe the technology of robots and predicted the rise of a powerful robot industry.

1942 - Asimov wrote "Runaround", a story about robots which contained the "Three Laws of Robotics":

A robot may not injure a human, or, through inaction, allow a human being to come to harm.

A robot must obey the orders it by human beings except where such orders would conflict with the First Law.

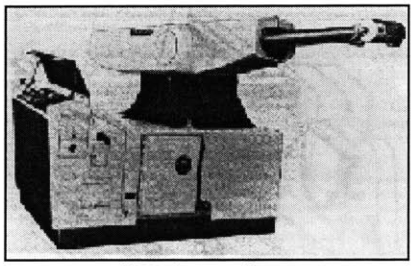
A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

1948 - "Cybernetics", an influence on artificial intelligence research was published by Norbert Wiener

1956 - George Devol and Joseph Engelberger formed the world's first robot company.

1959 - Computer-assisted manufacturing was demonstrated at the Servomechanisms Lab at MIT.

1961 - The first industrial robot was online in a General Motors automobile factory in New Jersey. It was called UNIMATE.



"Unimate"

1963 - The first artificial robotic arm to be controlled by a computer was designed. The Rancho Arm was designed as a tool for the handicapped and its six joints gave it the flexibility of a human arm.

1965 - DENDRAL was the first expert system or program designed to execute the accumulated knowledge of subject experts.

1968 - The octopus-like Tentacle Arm was developed by Marvin Minsky.

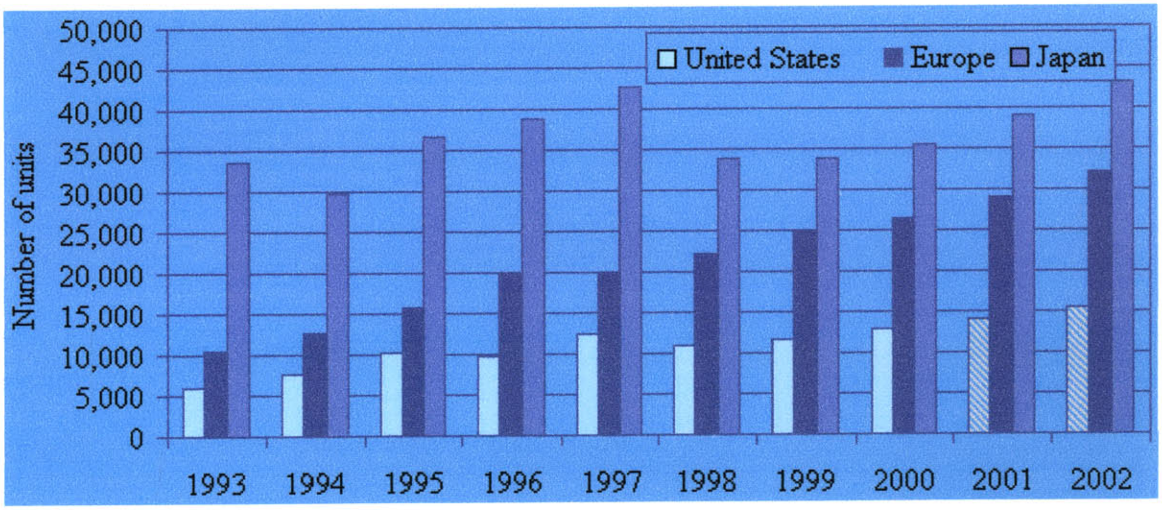
1969 - The Stanford Arm was the first electrically powered, computer-controlled robot arm.

1970 - Shakey was introduced as the first mobile robot controlled by artificial intelligence. It was produced by SRI International.

1974 - A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed.

1979 - The Standford Cart crossed a chair-filled room without human assistance. The cart had a TV camera mounted on a rail which took pictures from multiple angles and relayed them to a computer. The computer analyzed the distance between the cart and the obstacles.

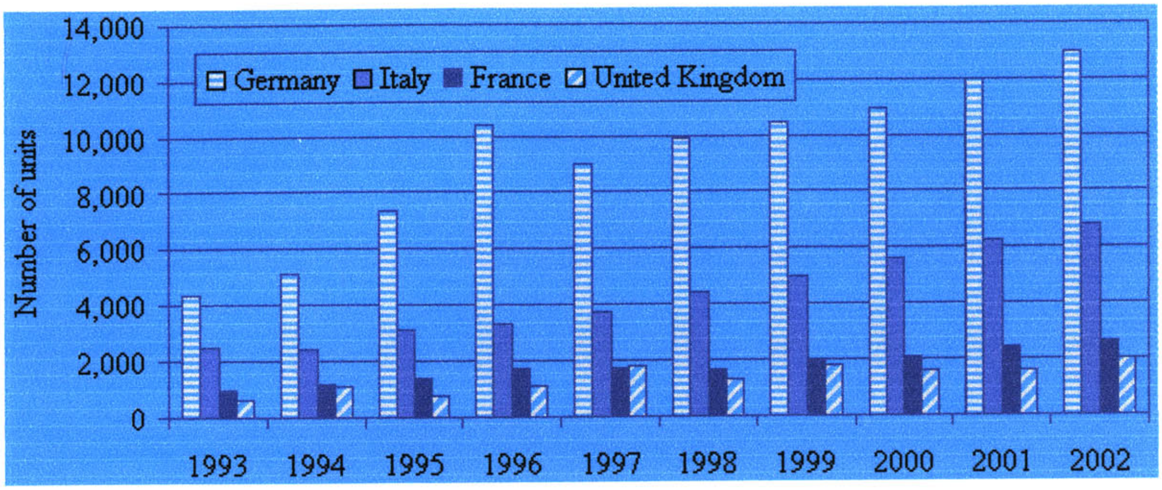
Since industrial robots began to be introduced to industries at the end of the 1960s, total worldwide accumulated yearly sales at the end of 1998 amounted to some 1,020,000 units. Many of the earlier robots however, have been taken out of service, and so the stock of industrial robots in actual operation is lower. The Economic Federation for Europe (EFE) and the International Federation of Robotics (IFR) estimated the total worldwide stock of operational industrial robots at the end of 1998 to be 720,000 units, with a projected stock of 800,000 units at the end of 2002. As seen from table 3, Japan accounts for more than half of the world robot stock, however its share is continuously diminishing due to the fact that the retirement of robots is higher than the new supply (in 1997, for example, more than two thirds of the Japanese supply were replacement investment.



Source: United Nations Economic Commission for Europe (UN/ECE) and International Federation of Robotics (IFR)

Table 3 – Worldwide Sales of Industrial Robots

It is worth noting that the growth in worldwide robotics is concentrated in North American and Europe. Between 1998 and 2002, sales of industrial robots in the United States are projected to increase from 10,900 units to 15,600 units, a total increase of 43%, or by an yearly average increase of just over 9%. In the same period the market in Europe is projected to increase from about 22,000 to about 32,000, an increase of 45%, or a yearly average increase of 10%.



Source: United Nations Economic Commission for Europe (UN/ECE) and International Federation of Robotics (IFR)

Table 4 – European Sales of Industrial Robots

Though the above numbers, statistics and tables indicate a definite growth in robot implementation, it is important to note that construction robots form a very small part of the supply. Most robots used are applied in the domestic and medical areas. The problems associated with the construction robot are discussed in section 4.3.

## 4.1 Robot Technology – Application in Construction Industry

*Robots for real-world factories can have large work envelopes, be branched, and can carry large and heavy workpieces if they are Cartesian and are electro-mechanical.*

*Clever end effectors eliminate sensitivity to work tolerances and the need for close or undefinable positioning accuracy.*

The Japanese Industrial Robot Association (JIRA), classifies robots into six categories, depending on the extent of their autonomy. The list below spans from the least degree of automation to the most (Warszawski, 1999):

1) Manual Manipulator (manually controlled)
2) Fixed Sequence Robots (can perform only a fixed sequence of operations)

3) Variable Sequence Robots (sequence of robot movements can easily be modified by an operator)
4) Playback Robots (led through the task by a human operator)
5) Numerically Controlled Robots (preprogrammed with external program)
6) Intelligent Robots (are able to interact with the environment)

Most of the above robots have been introduced in the manufacturing industry, where, according to Hasegawa (1986), the whole implementation process has been much accelerated due to the following reasons:

1) High utilization rate - low capital consumption per unit produced
2) Reduction in cost of computing equipment necessary to control robots
3) Mass-production –manufacturing industry is familiar with mechanization and has achieved a high degree of industrialization

On the contrary, robotic application in the construction industry is still at embryonic stages and unfortunately does not have many precedences. However, if properly used, robotization has considerable potential in this area. Three elements, chosen from the three most important problem areas in construction, contribute to creating the driving force:

- Improvement of working conditions onsite – aim to eliminate the four D's (or three K's in Japanese) of construction: dangerous (kiken), dirty (kitanai), difficult (kitsui), dull. Focusing particularly on the fact that construction is dangerous, it is relevant to note that the number of people who lost their life in the construction industry accounts for more than 40 per cent of the total industry. The introduction of robots into the process aims to improve these hazardous working conditions.
- Increase in productivity – improve efficiency of building process, improve quality (quality currently very much depends on the skill of the workers – substantial deviation in quality) and shorten the duration of the construction process thus reducing costs.
- Save construction labor – by introducing robots into the construction industry, the burning issue of shortage of workers will be much improved. Japan also suffers from

acute aging of construction workers (Warszawski, 1999), as construction sites are very unattractive to young people.

## 4.2 Developed Construction Robots

Each and every building activity has a very complex nature, which makes the robotization of such processes difficult and costly. The following table, illustrates the basic tasks involved in building construction.

| | Task | Description | Examples of Application |
|---|---|---|---|
| 1 | Positioning | Placing a large object at a given location and orientation | Erection of steel beams, precast elements, formwork, scaffolding |
| 2 | Connecting | Connecting a component to an existing structure | Bolting, nailing, welding, taping |
| 3 | Attaching | Positioning and attaching a small object to an existing structure | Attaching hangers, inserts, partition boards, siding, sheathing |
| 4 | Finishing | Applying continuous mechanical treatment to a given surface | Troweling, grinding, brushing, smoothing |
| 5 | Coating | Discharging a liquid or semi-liquid substance on a given surface | Painting, plastering, spreading mortar or glue |
| 6 | Concreting | Casting of concrete into molds | Casting of columns, walls, beams, slabs |
| 7 | Building | Placing blocks next to or on top of one another with a desired pattern | Blocks, bricks, or stone masonry |
| 8 | Inlaying | Placing small flat pieces one next to the other to attain a continuous surface | Tiling, wood planks, flooring |
| 9 | Covering | Unrolling sheets of material over a given surface | Vinyl or carpet flooring, roof insulation, wallpapering |
| 10 | Jointing | Sealing joints between vertical elements | Jointing between precast elements, and partition boards |

Source: Warszawski, 1986

Table 5 – Basic Tasks in Building Construction

There are four unique non-specific families of robots. The configuration and size of the manipulator are the two distinguishing features between the families listed below.

1) The Assembling Robot
2) The Interior General Purpose Robot
3) The Horizontal Finishing Robot
4) The Exterior Wall Finishing Robot

Each group will be looked at in more detail and examples of various prototypes will be illustrated.

### 4.2.1 The Assembling Robot

Automated assembly of prefabricated elements is an essential part of the realization of the industrialized-automated system with a minimum involvement of human labor. In order to accomplish this, a large-scale manipulator (Warszawski, 1999) may be adapted to assembling tasks, or, automated control may be superimposed on a regular crane onsite, allowing for full or partial preprogramming of the cranes movement. The typical work cycle of such a robot or crane, embodies picking up the load at its origin, transferring it to its designated location, placing it, and returning back to the origin to repeat the cycle.

Examples of such robots include:

- General handling robots

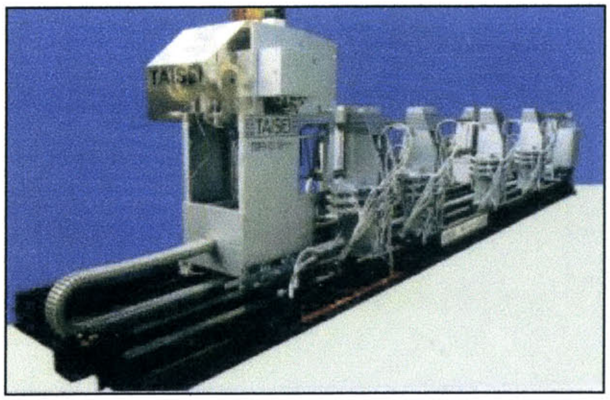


Figure 4.1 - Taisei Corporation, Reinforcing Bar Assembly Robot

- Tower cranes with automated control
- Reinforcement placing robots
- Automated concrete pumps (Ohbayashi)

4.2.2 The Interior General Purpose Robot

The general purpose of the interior finishing robot is to perform all the necessary tasks that cannot be included in the prefabricated elements, such as painting, tiling and plastering, most of which can be performed by one multipurpose robot. The main advantage of such a robot is that it allows a very high utilization rate and therefore lowers the employment costs.

- General load handling robots (Fujita)
- Robots for placement of boards (Taisei, Shimizu)

Figure 4.2 – Kajima Corporation, Board Placement

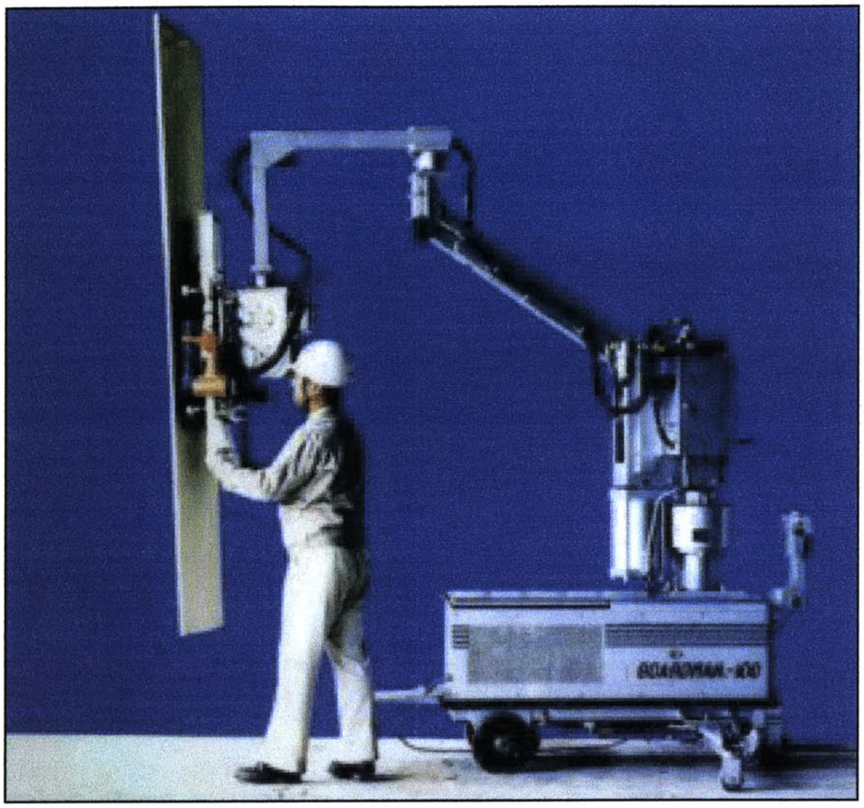


Figure 4.3 – Taisei Corporation, Wall Board Manipulator

- Robots for fireproof spraying of steel beams (Shimizu)
- Robots for masonry work (Bronco, Baumann)

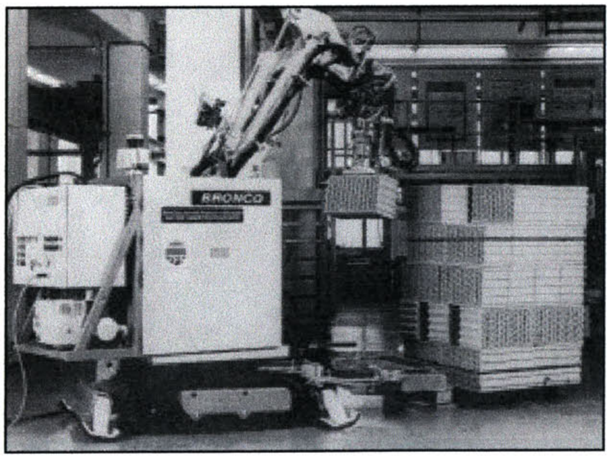


Figure 4.4 - BRONCO (University of Stuttgart), Automated Brick Laying Robot

- The multipurpose interior finishing robot (Tamir)

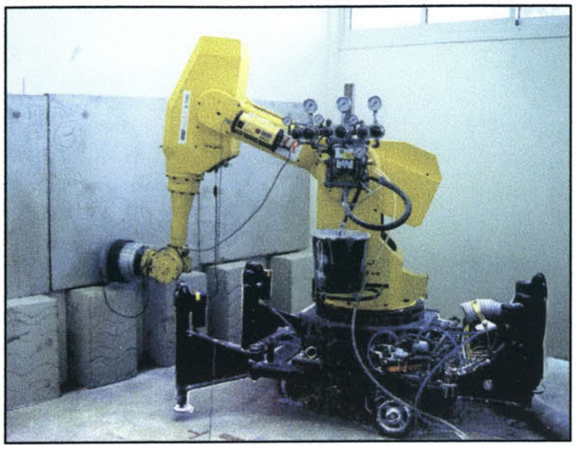


Figure 4.5 – TAMIR (Technion Institute of Israel)

### 4.2.3 The Horizontal Finishing Robot

Horizontal finishing robots may be used for finishing tasks on the concrete topping of the prefabricated elements. They can be used for troweling and/or for the application of a finishing coating.

- Troweling robots (Kajima, Obayashi, Shimizu)

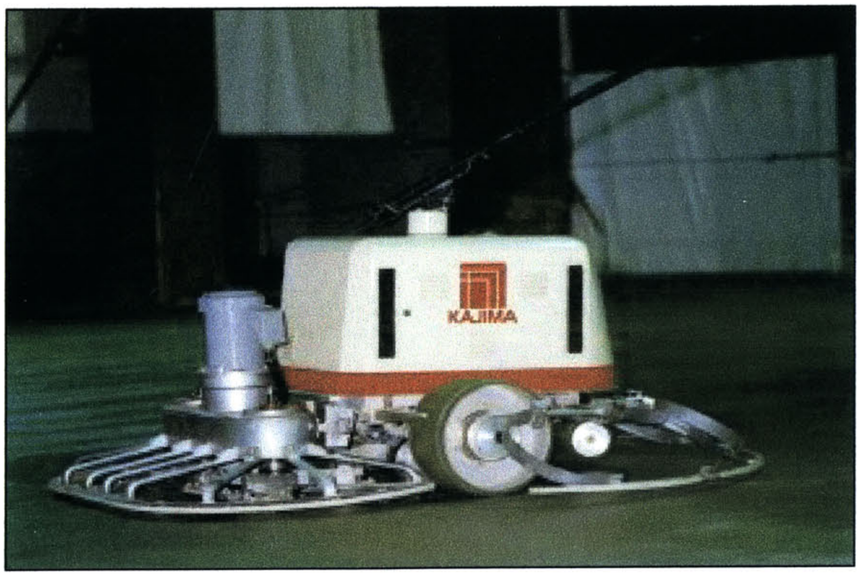


Figure 4.6 - Kajima Corporation, Kote-King, Concrete Floor Finishing Robot

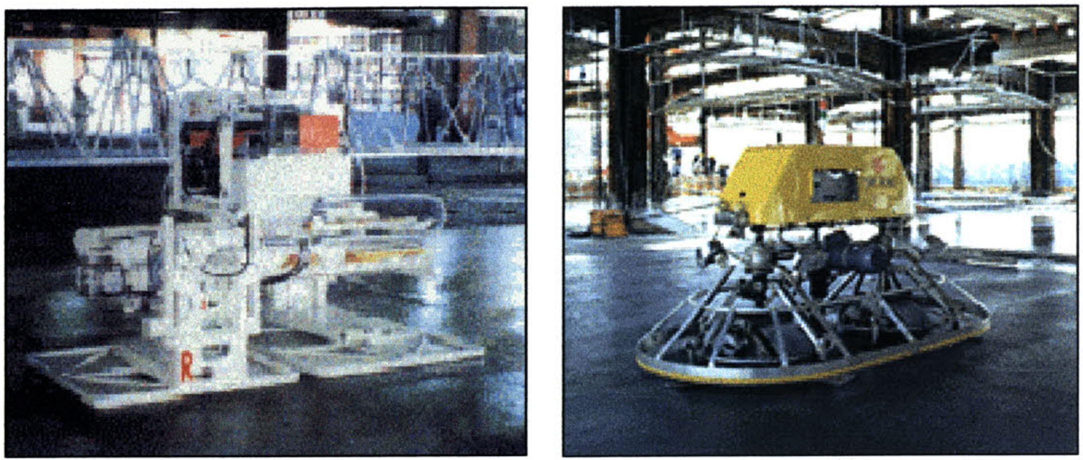

(a) (b)

Figure 4.7 – Troweling Robots: (a) Water absorbing robot; (b) Equipped with two sets of rotary floats, Surf Robo automatically finishes concrete floor surfaces

### 4.2.4 The Exterior Wall Finishing Robot

The functions of an exterior finishing robot include tasks such as painting, cleaning, jointing and inspection. The intangible benefits of safety, improved working conditions and quality of work, in this application are overwhelmingly obvious. The only drawback with this type of robot is that it is the most sensitive to nature of the buildings to which it is employed. Subsequently the installation of such robots are extremely complex, reducing their feasibility in small buildings and in buildings whose exterior shape and fenestration requires high involvement of manual labor.

- Wall painting robots


Figure 4.8 – Shimizu Corporation, Wall Painting Robot

- Wall inspection robots

According to Warszawski (1999), examination of the feasibility of the main generic robot types in conjunction with prefabricated assemblies for floor and wall elements, indicated the highest potential for use of robots being in the assembling and interior finishing aspect. Additionally, exterior finishing robots can easily be justified in terms of substantially higher degrees of safety and improved working conditions. Finally, horizontal finishing robots lack substantial justification due to the fact that they are only beneficial when fast finishing of large surfaces is required. Their efficiency needs to be examined with respect to mechanical non-automated devices of similar capacity.

## 4.3 Obstacles to the Implementation of Construction Robot

According to Hasegawa, the many problems that prevent the application of robotics in the construction industry, can be categorized into three major areas:

1) Technical problems
2) Economical problems
3) Organizational problems

### 4.3.1 Technical Problems

Whilst in the manufacturing industry industrialization is commonly found it is not so in the construction industry. There are many differences between these two industries resulting in the lagging behind of the latter.

One of the main difficulties faced by robots in the construction industry is the fact that, unlike in the manufacturing industry where products are transferred through a construction line, the structure remains in a permanent location and each individual crew goes to its allocated site. This implies that increased ease of mobility is required if robots are to ever substitute labor, which is currently one of the largest challenges .

The handling capacity required of construction robots represents an additional pitfall, as the components used in the construction industry are on average much heavier than those of the manufacturing industry are. Referring to Warszawski (1984), the typical handling weight of a manufacturing robot ranges from 50-200 lbs., in comparison to some of the components used in construction, which weigh several tons.

Probably one of the most apparent concerns is the fact that unlike the tasks found in the manufacturing industry, those typical of the construction industry require use of all functions of human labor such as sensing, walking, listening, handling and thinking. The repetition factor also comes into play, making use of lower level industrial robots difficult.

### 4.3.2 Economical Problems

Low utilization rate of construction machinery in construction makes firms reluctant to invest in such capital assets. People and companies are willing to invest millions to fully robotize a mission to Mars, however, fully automating the construction of a building is not motivating enough. The required driving force for the small contracting companies is non-existent. Nevertheless, even if the encouragement was there, once again firms would be reluctant due to that fact that there is never a guarantee that projects, and thus income, will exist tomorrow.

### 4.3.3 Organizational Problems

As has been repeatedly mentioned, the construction industry is highly fragmented, consequently no single firm can take initiative in any particular project. Thus, it is difficult for a construction firm to develop a robot without cooperating with a large number of establishments outside their own industry.

## 4.4 Strategies to Successfully Introduce the Construction Robot

Taking all the above into account, it is evident that the first step is to introduce construction robots within the framework of the construction industry. Secondly, capital intensity must be attained for the successful introduction of robots (Hasegawa, 1987). If the business, social and political environment remain as they are, intensive investment in construction machinery is prevented, and so it is not economically feasible to invest in construction robots. The solution to this problem is to fully utilize construction machinery, hence decreasing the cost of capital goods per production.

The third, and most important way to introduce robots to the construction industry, is to achieve cooperation between a number of sectors, primarily in order to allow for risk sharing. Additionally, by cooperation, construction robots can generate additional benefits to each sector rather than limiting their activity to one. There are many different combinations of sectors, a couple of which are construction industry-service sector, and construction industry-manufacturing industry-service sector.

# Chapter 5 - Setting the Scene

The central premise of Alvin Toffler's book on the third wave, was that human history, while it is complex and contradictory, could be seen to fit patterns. The pattern he has been seeing in his career takes the shape of three great advances or waves. The first wave of transformation began when some prescient person about 10,000 years ago, probably a woman, planted a seed and nurtured its growth. The age of agriculture began, and its significance was that people moved away from nomadic wandering and hunting and began to cluster into villages and develop culture.

The second wave was an expression of machine muscle, the Industrial Revolution that began in the 18th century and gathered steam after America's Civil War. People began to leave the peasant culture of farming to come to work in city factories

Just as the machine seemed at its most invincible, however, intimations of a gathering third wave were being received, based not on muscle but on mind. It is what is variously called the information or the knowledge age, and while it is powerfully driven by information technology, it has co-drivers as well, among them social demands worldwide for greater freedom and individuation.

The construction during the late 19th up to the mid-20th Century can be identified by one predominant structural form -- the High Rise. This type of structure was usually constructed with either concrete or steel. The first tall structure using steel as its principal building material was the Eiffel Tower in Paris (Figure 5.1). But the major innovation was the development of the steel frame, as a structural element. The home of the high rise is Chicago, where the first metal structure was built -- the 10-story Home Insurance Company Building in 1885 (Figure 5.2 - demolished in 1931). The metal framing used in this building was completely encased in brick so as to render it fireproof. The Manhattan Building (Figure 5.3) was the first to use vertical truss bracing to resist wind forces. The first all-steel building was the Ludington Building in 1891 (Figure 5.4).

In the years after World War II, glass was used extensively in high rise structures, culminating in the curtain-walled skyscraper. But the efficiency of such high rise structures was possible only after the development of rubber as a sealant, artificial climate control, and through the use of aluminum as a building material. One of the major landmarks in curtain walled structures was the United Nations Secretariat Building (1949) in New York City (Figure 5.5).

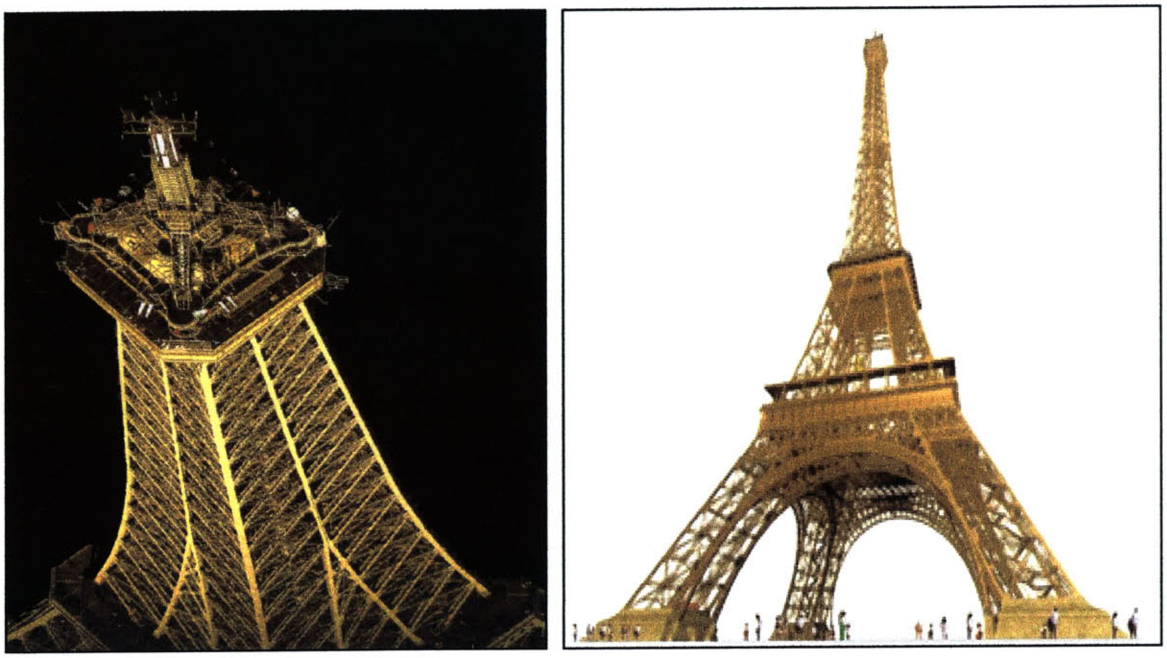


Figure 5.1 – Eiffel Tower, Paris

Figure 5.2 – Home Insurance Company Building, Chicago

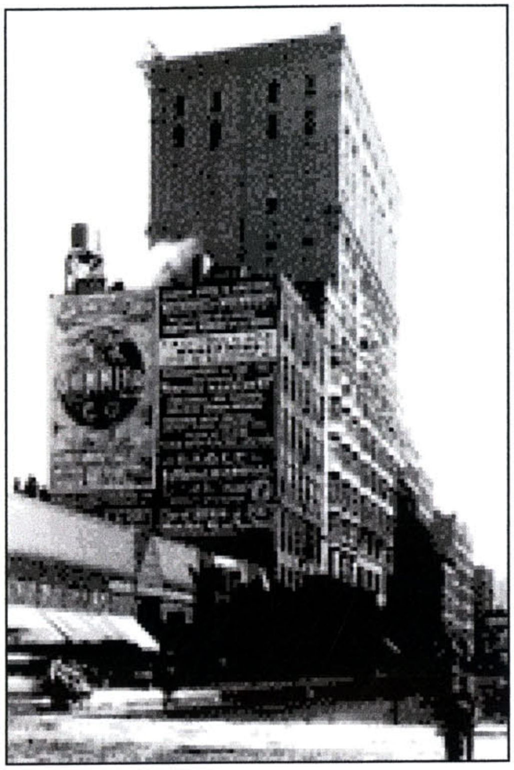


Figure 5.3 – Manhattan Building

Figure 5.4 – Ludington building, Chicago

Figure 5.5 - United Nations Secretariat Building, New York City

Concrete shear walls were used in tall structures to provide resistance against the lateral forces of wind and earthquakes. The wall acted as a cantilever beam in this case. Another form developed was the perimeter-framed tube form. In this form, closely spaced concrete columns were placed on the perimeter of the building and were connected by deep beams. The next step was combining the tube form with a central shear wall core added for stability. Diagonal bracing was also developed. Development of lightweight concrete, increased strength of concrete and the use of pumps to deliver concrete to upper levels were the major contributing factors for the popularity of concrete as a suitable material. Also, reinforced concrete, that is concrete combined with steel rods, was a significant development.

The developments during this period have led to construction practices that have become standard for buildings and continue to be so even today. Skyscrapers are the expression of architectural and construction expertise of this century.

Focusing more on the current situation, the construction industry is in its ninth consecutive year of growth. The overall health of the U.S. and world economies has driven this expansion. Low domestic interest rates, predictably low rates of inflation, and the improved fiscal position of the federal and state governments have spawned increased construction work within the United States. As a result, the U.S. industry is vibrant and robust and maintains a huge competitive advantage in the domestic market, which represents over 20 percent of the $3.6 trillion world market (Engineering News Record, 1996). Internationally, the U.S. industry is beginning to compete more successfully as it exports many of the skills at the root of its domestic dominance: design, construction management, safety, and quality.

Construction spending has steadily increased each year over the past decade, with an almost 35 percent increase in the total value of new construction since 1990. For 1999, the industry committed over $700 billion to new construction and put in place nearly $200 billion in additions, alterations, maintenance, and repair work

This overall pattern of increased spending is expected to continue into 2000 with an 8 percent increase over 1999 (US Census Bureau). However, construction spending is very sensitive to interest rates, and slowdown in the pace of construction work is expected for the near term as the government increases interest rates in order to keep inflation under control.

The United States is the world leader in the construction industry. This nation's firms have a particular advantage in the areas of project design, management, environmental controls, safety, and construction quality. Numerous overseas projects are proudly described as "meeting American standards." Such benchmarking of U.S. quality is a vivid indicator of the industry's strength, solid reputation, and leadership abroad. Last year, most exports of U.S. construction services went to the Asia–Pacific region (45 percent), followed by Latin America (25 percent) and Europe (15 percent). The overseas market represents a significant growth opportunity for U.S. firms, especially the rapidly industrializing countries of East Asia and Latin America.

By contrast, foreign construction contractors have made few inroads into the U.S. market. In 1998, foreign firms accounted for less than 10 percent of the U.S. construction market. However, acquisition of U.S. companies by foreign firms is growing, and U.S. contractors face strong competition at the highest end of the spectrum from large foreign firms that can successfully execute "megaprojects." A union–versus–non-union divide is one of the more salient characteristics of domestic construction labor. Another, is a shortage of skilled labor. The shortage of skilled labor, including craftsmen, engineers, and managers, is the most daunting challenge to the construction industry. Although the industry is in its ninth year of expansion, there are not enough skilled workers to meet the current market demand. In fact, the Bureau of Labor Statistics estimates that the construction industry needs to recruit and train 240,000 workers each year to replace those leaving the industry and to accommodate the industry's current growth. This need far exceeds the 50,000 new workers entering the industry each year. If the current shortfall continues, it will eventually sap the industry's strength and productivity, constrain its growth, and drive up costs.

This difference in the labor situation around the world is a potential reason why future innovations may differ from country to country. As mentioned above, the driving force behind most innovations in construction in this labor shortage. In countries like Japan, where this problem dominates the industry, major technological innovations may take place, as those considered in Chapter 3 and 4. On the contrary, due to the aforementioned situation, both the U.S. and Europe rely very heavily on imported guest laborers, and so do not have that motivation, the "shortage of labor" driving force does not exist. This may result in advances towards the development of innovative techniques for better integration of human resources such as Quality Circles and the implementation of the managerial approaches, discussed in Chapter 2.

## 5.1 Future Trends

The latter half of the 20th century has seen unprecedented social changes in the world in terms of population growth, technological revolutions, worldwide urbanization and poorly-controlled pollution and creation of waste. These unparalleled changes in the evolution of the industrialized information technology era have created insatiable demands not only for infrastructure regeneration and rehabilitation, but also for a more equitable distribution of the world's material and energy resources. These global changes have had a great impact on the construction industry, and because the construction industry is so much interlinked with energy, resources and the environment, a sustainable development in construction processes and methods alone can help prevent unredeemable environmental degradation, while simultaneously improving the quality of life.

As described in the previous chapters, recent innovations, such as the use of Quality Circles (on the organizational end) and the implementation of robotics (on the technological end) all have potential to increase productivity, while concurrently not harming the environment.

However, future developments will undoubtedly demand more innovative and creative thinking on the part of the engineer, architect and designer. Currently, there are a number of visions for the future, with the main aim being to eliminate the problem of limited space while simultaneously protecting the environment. This challenging task requires the cooperation between sectors, in order to share the risk of stepping out of line.

### 5.1.1 Conceptual Futuristic Innovations in the Construction Industry

The human mind constantly craves to produce shortcuts – people try and reach the same goal faster, more efficiently, all the time. In a way our mind is a complex value engineering system, attempting to achieve more with current resources, or achieve the same with fewer resources. The author is a firm believer that the driving force behind future innovations will be the ever-increasing demand for land, accompanied by a similar decrease in availability.

Urban growth is changing the face of the earth and the condition of humanity. In one century, global urban populations have expanded from 15 to 50 per cent of the total, which itself has gone up from 1.5 to nearly 6 billion. In the year 2000, half of humanity lives in cities, with much of the other half depending on urban markets for their economic survival. Urban agglomerations and their resource uses are becoming the dominant feature of the human presence on earth, profoundly changing humanity's relationship to its host planet and its Eco-systems. Will it be possible to limit the physical impact of cities on the global environment?

The era of underground construction will soon begin. There are a number of solutions to the limited space issue. One is the aforementioned application - efficient utilization of underground spaces. Susan Nelson, Executive Director of the American Underground Association, provides a thorough explanation as to the benefits of underground construction, especially in urban areas.

> "Not only is the surface preserved for other uses, density can be increased without contributing to surface crowding. Other benefits include temperature stability, energy conservation, easily controlled climate, and avoidance of conflicts with other surface uses. In a sense, when the subsurface is utilized, leaving the surface

> free for other uses, the land can be used twice. If air rights are also involved, the land is used three times.
> There are few limits to what can be put underground. In Scandinavia, for instance, wastewater treatment facilities are routinely sited underground. This has the benefit of removing a nuisance from the surface, while also allowing the facility to be sited closer to the "source," reducing the length and cost of conveyance facilities."

When asked what changes in the underground technique are foreseen in the next five years, Wolfgang Roth, Principal Engineer and Vice President of the URS Corporation, claims:

> "Five years is a rather short period for changes in underground construction techniques to occur--particularly in the US, where many owners and design consultants still "hide" behind the contractor when it comes to selecting tunneling means & methods. Add the fact that US public works contracts are awarded to the lowest bidder, and you have a powerful incentive against using advanced tunneling technologies. Why would any contractor jeopardize his low bid with expensive tunneling machines, unless they are specifically required in the bid documents? -- Especially if the downside risk of selecting low-cost means and methods is likely to be covered by construction claims? Given this situation, I believe that the most significant changes in the next five years will be in the way of contracting for underground construction, rather than technology per se."

According to Andrew D. Walker, President of Nicholson Construction Company, in the future, the majority (more than 50%) of this work will be carried out using underground mining methods, with the populous unaware of the work going on below their feet.

### 5.1.2 Initial "Blossomings" of Future Innovations

Underground parking has been around for a long time, however a new system, referred to as TreviPark, offers cost effective fully automatic, unmanned underground or over-ground car parking solutions, particularly for tight sites in urban areas where space is at a premium.

Vehicles are parked at street level, with nobody entering the silo. Once parked, the vehicles, which can either be cars or light vans, are totally safe, being both vandal-proof and secure from theft or damage. Parking and retrieval times are identical, averaging 50 seconds per car. Operation can be free or payment-based if applicable and can be effected by way of credit card, dedicated card or cash.

Whilst Treviparks come in all shapes and sizes to suit a particular site, a standard silo will accommodate 72 vehicles in an area measuring 21m$^2$; the car park can be built over on completion. The entry and exit positions are normally separate, where space will allow, but if there is not sufficient space, the entry and exit positions can be combined.

This is a promising innovation, as the efficiency is truly remarkable and the result is completely inconspicuous. Generally the most effective use of available space requires the parking area to be circular, built around a main lift unit. This does not stop the same technology being used for conventional rectangular formats, by the inclusion of a lateral travelator on each level.

The construction procedure and end result is illustrated in Figures 5.6-5.8. The diaphragm wall can be constructed as secant piles, metal sheet piling or a special patented method of continuous diaphragm wall developed by TreviSpA. in Italy. After the diaphragm wall has been constructed the soil is excavated from the middle and a cast concrete slab installed at the bottom to take the lift machinery. The structure can be completed, in the majority of cases within 6 months form conception.

Figure 5.6 – Construction of a TreviPark

These structures can also be located in courtyards and gardens, allowing for their implementation into city locations without compromising the environment of the areas concerned.

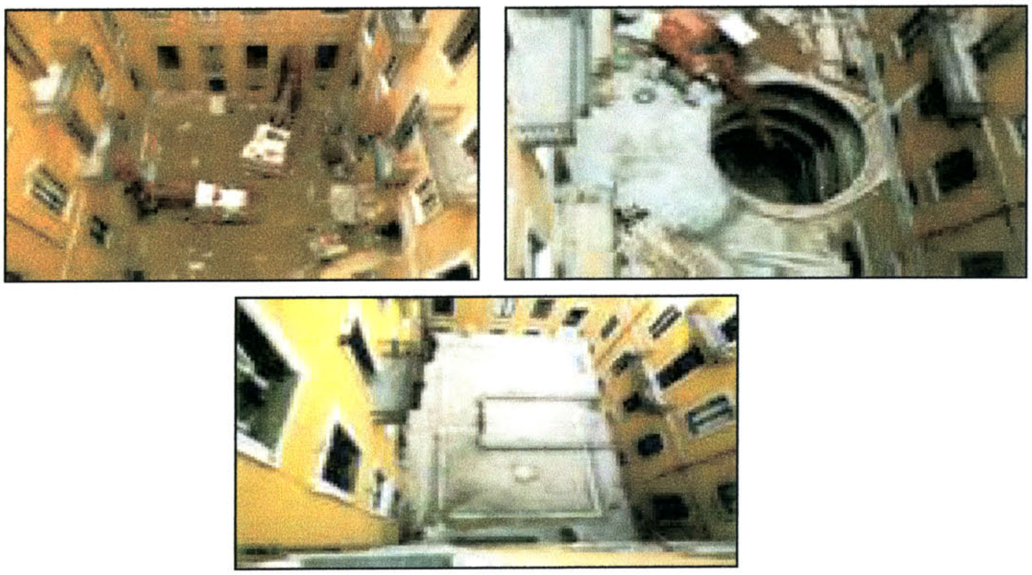


Figure 5.7 – Construction within Courtyards and Gardens

Some examples of their ability to camouflage as well as their efficient usage of space, in comparison to a traditional parking lot are illustrated below. It is interesting to note that with a diameter of approximately 20m they can hold more than 70 cars.

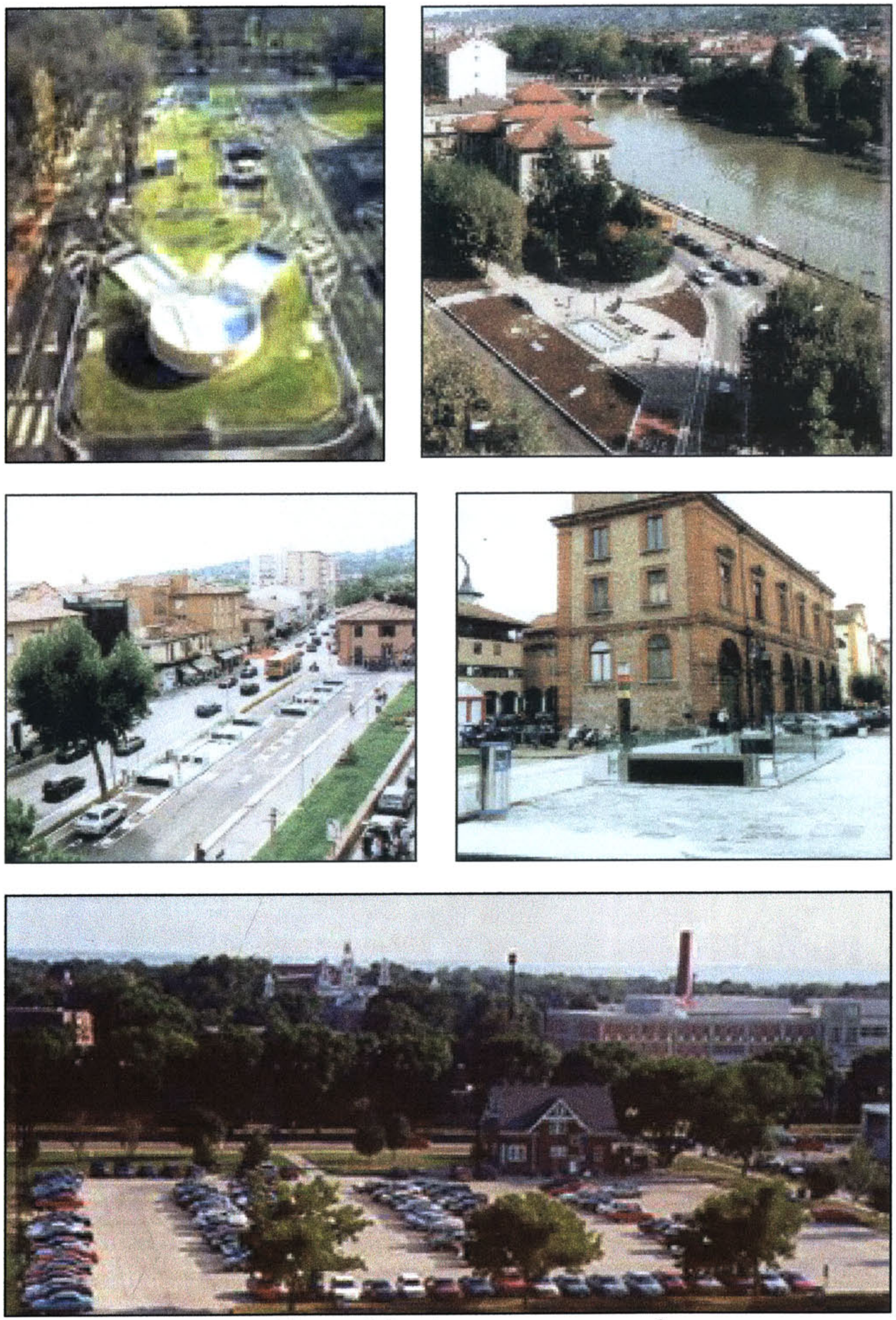


Figure 5.8 – Appearance comparison

A second solution to the limited space and energy issue, which is yet in the conceptual stages in Japan, is the construction of megastructures. Most people may be more familiar with this concept from "The Fifth Element", illustrated in Figure 5.9. In this film, one of the reasons that the future is so easy to control is that the city is a giant series of megastructures. A megastructure is defined as a "single, vast, unified structure, encompassing all areas of human activity" (Corn 55). The buildings hold many thousands of people and are miles tall.

Figure 5.9 – "Fifth Element" Megastructure

Just as impressive is the idea of floating megastructures at sea, which involves the construction of these megastructures, followed by their towing to locations where they would be most beneficial, and finally anchored to the ocean floor (Figure 5.10).

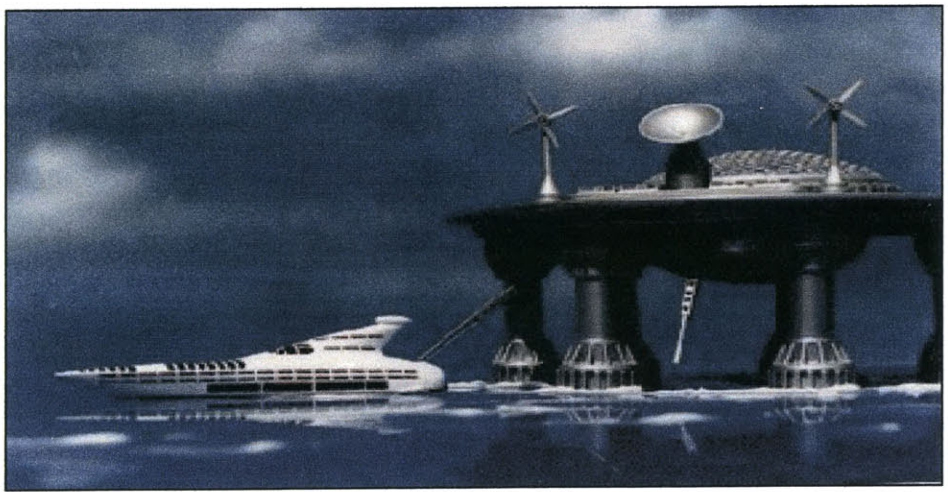


Figure 5.10 – Floating Megastructure

An additional benefit is that well designed high-density residential developments tend to require less domestic energy consumption. Terraced houses and flats generally lose less heat than detached houses, whilst policies to improve insulation, increase passive solar capture and to provide appropriate shade can all help reduce the energy costs of running an urban household. Postulating from the aforementioned statement, megastructure construction will decrease the energy requirements, thus alleviating demand.

In the 1880s and '90s, artists "foresaw" impossibly dense and congested cities, filled with shockingly tall skyscrapers, the air crowded with bizarre airships. By the mid 1950s this became a reality and many if not most became true. These may seem substantially futuristic, however as the demand is so high, it is the authors opinion that these developments will arrive much sooner than expected

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