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A STUDY OF APPLICATIONS AND EFFECTS OF EMERGING AUTOMATED AND INFORMATION TECHNOLOGY IN CONSTRUCTION

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CHAPTER I

THE CONCEPTS OF AUTOMATION AND INFORMATION TECHNOLOGY IN CONSTRUCTION.

1.1 Introduction

The use of the Information Technology (IT) can help in the construction process from several points of view. An information system is a work system that uses information technology to capture, transmit, store, retrieve, manipulate, or display information, thereby supporting other work systems. Computer and communications technologies have revolutionized the way most industries work. The impact starts with the increment in productivity. Its applications have changed the workplace characteristics. The importance of IT in all layers of society has expanded greatly.

The following outline enumerates some of the tasks that are being solved or can be solved by the IT in the construction industry.

1) Management and Administration

   a) Accounting and Payroll
   In larger construction companies, computers often appeared first in accounting departments. The most complex part of a contractor's accounting system is often payroll.

   b) Cost Engineering
   As a minimum, a cost-control system enables a contractor:
      i) To break a project down into categories that make sense from the point of view of the crews and supervisors doing the work.
      ii) To accurately reflect progress with respect to the planned budget.

   c) Company and Project Finance
   At a high level, developer-builders can compare alternative sites, building types, design and construction schedules, and possible types of tenants or buyers in a local real estate market and try to project expenditure and income streams to develop discounted cash flows.

   d) Project Planning and Scheduling
   Scheduling programs on computers typically start with basic CPM or PERT computations. (An example is Primavera Project Planner).

   e) Materials Management
   Effective materials management is essential to the technical and financial success of any project.

   f) Equipment Management
   Effective equipment management is tremendously important for resources optimization.

   g) Human Resources Management
      i) Skill inventories
      ii) Employment history
      iii) Contact information

h) <u>Office Administration</u>
Word-processing software can assist with letters, transmittals, reports, etc.

i) <u>Education and Training</u>
IT enhances the effectiveness of education and training.

2) <u>Construction Engineering</u>

a) <u>Estimating</u>

i) Maintenance and preparation of master checklists.
ii) Quantity take-off.
iii) Productivity and cost analyses.
iv) Compilation and organization of summary and backup computations.
v) Compilation and analysis of subcontractor bids.
vi) Distribution of overhead and indirect costs.
vii) Modeling for sensitivity analysis of alternatives and contingencies in determining markup.
viii) Preparation and delivery of the bid or proposal.

b) <u>Productivity Improvement</u>

i) Compilation and analysis of questionnaires.
ii) Simulation of operations.
iii) Productivity and cost analyses.
iv) Control of equipment (manipulators, robots, etc.).

c) <u>Quality Assurance</u>

i) On line retrieval of specifications, codes and standards.
ii) Direct production control.

d) <u>Surveying</u>

i) Use of GPS
ii) Microprocessor controlling theodolites
iii) Distance measuring devices

e) <u>Computer-aided Engineering Analysis</u>

i) Structural Design and dynamic analysis
ii) Concrete form design
iii) Pipe network layout and flow calculations

f) Computer-aided Design and Drafting
The use of 3-D and 4-D CAD gives new possibilities in the design and construction.

1.2 Special characteristics of the Construction Industry

Factory-based manufacturing industries have long been enjoying increasing economic, safety, and quality control benefits from automated data collection and from the process control of production operations using automated machines, including robots. However, field-oriented industries like construction, with frequently reconfigured operations and often-severe environmental conditions, have been slower to adopt the information and automation technologies.

The major differences between construction and a typical manufacturing process are analyzed by Warszawski [1]

Table 1.1. Main Characteristics of Construction and Manufacturing Industries.

MAIN FEATURES OF CONSTRUCTION VERSUS MANUFACTURING INDUSTRIES

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 typical project
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 product
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 turnover of workers
Unified decision-making authority for design, production, and marketing	Authority divided among sponsor, designers, local government, contractor, and subcontractors

There exist at least six characteristics in the construction process that complicates the introduction of Information Systems (IT) and Automation. These are:

I. Complexity of Building Process.

The construction process includes a big number of different skilled trades. Because of the large quantity of functions a building will furnish, there is a large number of works that must be coordinated and adapted to each other in the finished project. The success of the usage of new information techniques will depend on the level of coordination obtained for all these different works. *This implies a coherent strategy for the use of this new technology both within individual companies and practices, and within the wider construction process*

Figure 1.1 shows an example of the organizational and management structure for a large construction project [2]. This can be taken as an example of the complexity of the building process

II. Distinctive Nature of Projects

Each user has different needs, habits, and preferences. The question of a higher standardization is still under debate. *The prevailing trend is to move to standardization as long as it does not affect the overall quality and aesthetics of each solution.*

III. Dispersion of Construction Activity

The construction process is fragmented. Considerable part of the building project can only be carried out at the present state of technology, only onsite.
One of the problems faced is how to maximize, as much as possible, the share of construction work that can be performed at an offsite-centralized facility.

IV. Divided Authority

Every building project contains inputs from several factors that in many cases act independently of each other: sponsor, designer, and contractor. A divided authority reduces the overall efficiency of a solution. For improving efficiency it is necessary to use a decision-making strategy that includes [3]:

a) Define and communicate the goals for and concerns about the project.
b) Identify areas and levels of performance that are critical to these goals
c) Establish value frameworks against which to assess the solutions.
d) Translate stakeholders' requirements to terms that they can be more readily dealt with.
e) Raise and assess potential solutions in terms of their relative values.
f) Communicate and coordinate the "product" description during the project's life cycle.

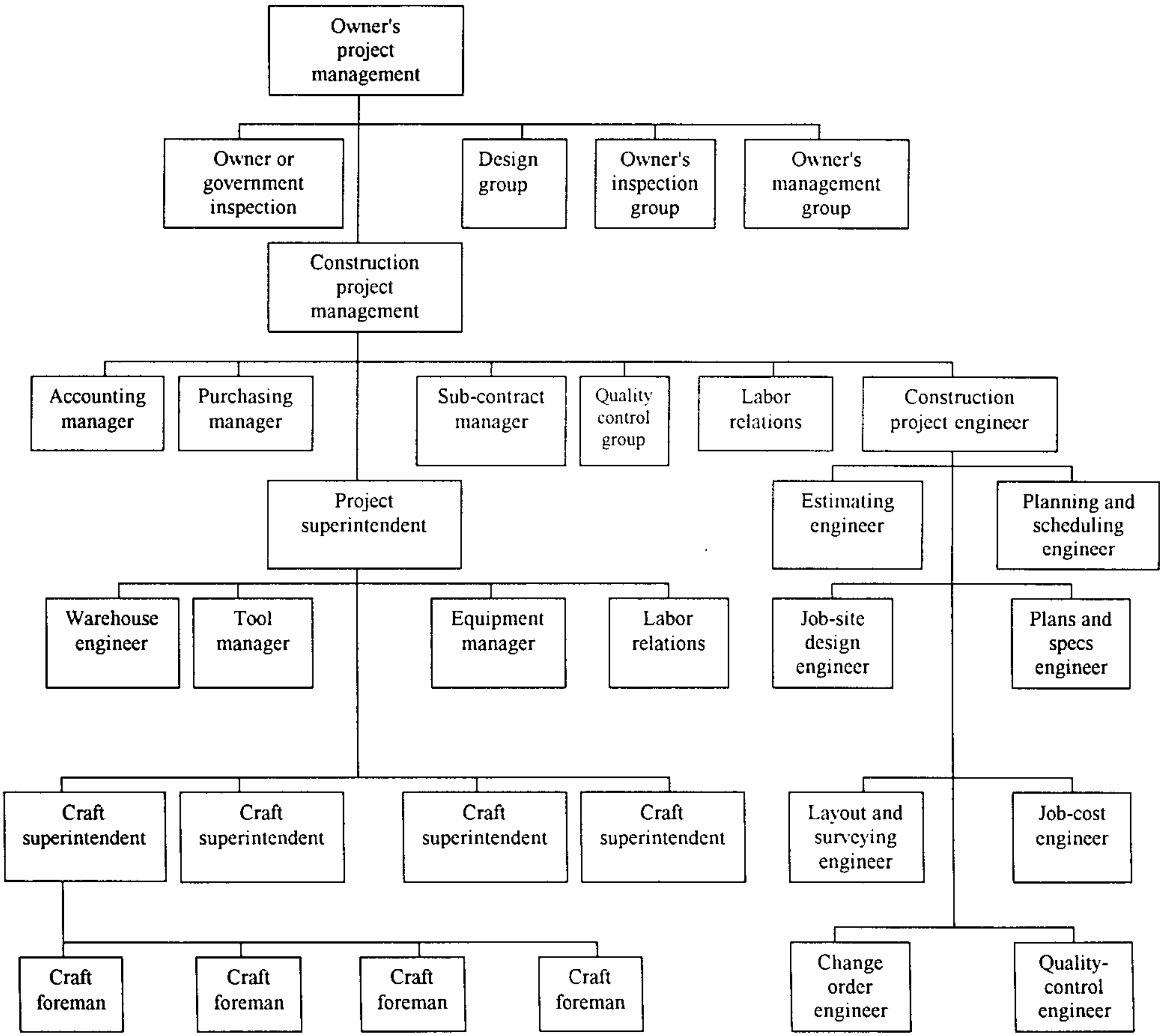

Fig. 2.1 Organizational and Management structure for a large construction project.

To attend the observed needs in a) through f), it will be necessary to clarify:

i) What decisions will be made and when?
ii) What information is needed and in what form?
iii) Who should contribute to these decisions?
iv) Who should communicate them to whom?

V. Work Environment

Construction often demands that workers do hard physical tasks outdoors in all kinds of weather. Also there exists the need to move continuously from one location to another.

VI. Long Service Life

Building projects are formally expected to function 50 years or more. The quality of buildings is therefore very important and should be ensured with appropriate design and careful control during construction and take into account that the users needs and lifestyle will change during this relatively long time. The ideal solution could be a "flexible" building that can be adapted, by easy modification of its components, to changing user requirement or special maintenance needs.

1.3 Flow of Information on a Construction Project.

In a very simplified way, the flow of information on the construction site may be represented as follows (Figure 1.2) [3]:

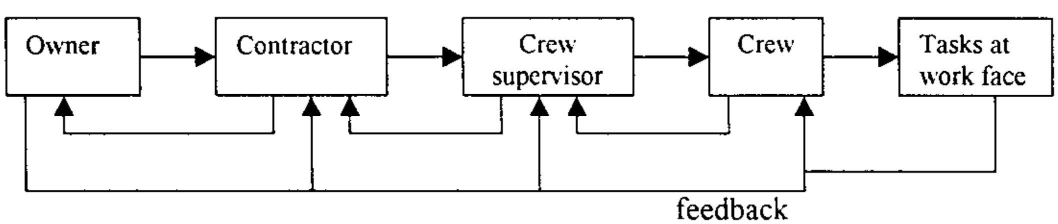

Fig. 1.2. Flow of information on the Construction site.

The communication of any kind involves a very complex process and is very strongly influenced by those who generate and transmit it. Besides this, informal communication usually occurs which can have a marked effect on productivity.

If the construction process is analyzed from the beginning, the problem becomes more complicated. Traditionally, the building delivery process has been managed as a series of discrete activities that are supposed to be controlled from the project team. This situation is represented on figure 1.3. [3].

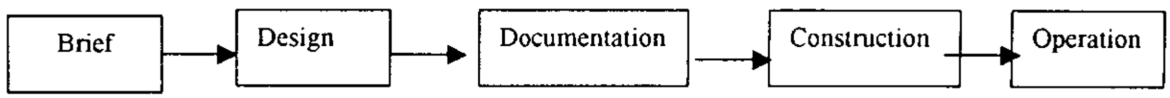

Fig. 1.3. Traditional Fragmented Project Description.

The information produced by each stage is described by Sanvido [4].

1) Design information: drawings, material schedules, specifications, simulations and calculations.
2) Execution information: contracts and change orders, government codes and regulations.
3) Business information: cost, schedule, resource and quality models.
4) Construction information: resource and work method plans.
5) Operating information: operating manuals and as-built drawings.

In traditional construction, this information is usually not integrated. The used terms and standards are different and it is frequently developed and owned by different organizations. In order to overcome the difficulties presented by the poor organization of information in construction projects it is necessary to move to what is called the Computer Integrated Construction (CIC). This involves the "application of computers to better manage information and knowledge in their various forms with the goal of totally integrating the managing, planning, design, construction and operation of facilities." [3]. The CIC is part of a more general branch called Information Technology (IT).

In order to effectively use the IT the users need:

1. A clear definition and architecture to organize classify and manage the required information.
2. Tools for modeling the processes associated with the construction.

1.4 Information Technology (IT) Application.

In order to successfully apply the information technology to any system in particular to construction projects, it is necessary to focus the attention on five perspectives [5]

1. Architecture: Specifies how the construction project operates, summarizing all the components (participants), the way they are linked, and the way the components operate together.

2. Performance: Describes how well the construction project, its components, or its products operate. Because project performance depends on the balance and alignment between all the project components, improving the performance of just a part of the project may not affect the results if the other parts are left unchanged.

3. Infrastructure: Is the human and technical resources the construction project depends on. For information systems, the technical infrastructure typically includes computer networks, telephone systems, software for building and operating these systems, and automated machines. The human infrastructure is the support staff that keeps them operating effectively.

4. Context: Is the organizational, competitive, technical and regulatory conditions within which the construction project operates, including external stakeholders, the organization's policies, practices, culture, and the competitive and regulatory issues that affect the project.

5. Risks: Consists of the events that may prompt the project to fail in any of its parts.

Leslie and McKay enumerated the benefits of information technology application in the construction industry [3]:

1) Gain access to the stakeholder definitions of product quality and value.
2) Communicate performance requirements and flag subsequent action needed by others.
3) Coordinate with other team members in making decisions.
4) Monitor decisions and actions to ensure that interim conditions for meeting all the project's performance goals prevail.
5) Manage alternative solutions while related optimizations tasks are in progress.
6) Check for a certified compliance with stated performance requirements.

When automated machines and robots are included, the following could be added:

7) Better use of machine's efficiency.
8) Minimization of power consumption.
9) Determination of optimal combination of machines.
10) Just -in-time supply of the machines for the construction site.
11) Use of machines in places where the tasks are repetitive or dangerous for the workers.

The major driving forces for information and automated system applications in construction are as follows [6]:

1) Extensive lack of skilled workers and a growing average age of the staff.
2) Demands for effective humanization of nearly all construction works.
3) Increased requirements on the quality of the work execution.
4) A need for works in dangerous and inaccessible areas of operation.

5) An increase in performance and reduction of costs for improvement in economy.
6) The competition on international markets of construction machinery.

Among the major barriers that may be encountered [7] are:

1) Difficulties in standards introduction due to the interaction between large number of bodies.
2) The benefits of installing the new technology may be relatively low unless every participant in the grouping has and uses it.
3) The degree of support exhibited by top management.
4) Problems related to the technology installation on-site.
5) The different educational and cultural backgrounds of the people involved in the construction.

1.5 The Creation of a Model or Computer-based Description of Construction Projects.

The success of Computer Integrated manufacturing (CIM) is a good basis to think about the possibility of a wider use of communication, computers and automated machines in construction. Field oriented industries, like construction, have been slower to adopt these technologies. In the previous paragraphs some of the more important barriers for this application were enumerated. All this could be presented in one general conclusion: *The lack of coherent strategy for the integration of these technologies within a company is the basic constraint of their effective use within the organization.*

A main task of automation in the construction industry should be to increase the possibilities of information interchange, not only between locations or companies, but also between computer-applications in one system. Several works have been developed moving towards the creation of standards and also an information architecture to integrate the necessary information for managing, planning, design, construction and operation of a building [1] [3] [4] [8] [9].

For creating such models or computer-based description of a project, it is necessary to know:

1) The information requirements.
2) The methods of processing the information
3) The format of the information.
4) Steps during the project realization
5) The criteria for making decisions.
6) A method for the measurement of the success in executing the project.

1.6 Conclusions

1. The wide implementation of information technology in construction has proved to be a difficult task due to the characteristics of the construction industry. In spite of these conditions, the introduction of the new techniques is inevitable because of five characteristics that are also present in the construction work:
   - Dirty environment
   - Hard working conditions
   - Dangerous working places

2. One very important element for obtaining the integration of the construction process is to move to standardization as long as it does not affect the overall quality and aesthetics of each project.

3. It is desirable to increase, as much as possible, the share of construction work that can be performed at an offsite-centralized facility.

4. Field oriented industries like construction, with frequently reconfigured operations and often-severe environmental conditions have been slower to adopt integrated computer-based communication and automation technologies.

5. In order to make rational use of the new technologies in construction, it is necessary to increase the possibilities of information interchange not only between locations or companies, but also between computer-applications in one system.

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CHAPTER II

BUILDING CONSTRUCTION PROCESS INTEGRATION

2.1. Introduction

The integration of design, planning, and construction offers important opportunities to improve performance on engineering and construction projects. This integration requires Information Systems (IS) that supports the communication between the different participants. Nowadays most participants in a building project perform their activities aided by computers. In contrast, the communication between participants is carried out in the majority of the projects with conventional media (for example through drawings, specifications, etc.). The process of interpreting and understanding the exchanged information is carried out by human beings. In order to improve this situation, it becomes mandatory to support this exchange of information by IS. This implies the use of models for representing the different participants in the construction process and standards to exchange the model's data.

2.2. Coordination Between Participants

The building process is often seen as a linear process from early investigations to the maintenance phase [1]. The main phases, as a rule, are broken down into sub-phases. Planning and design are activities pertaining to a model of a future building to be erected. The construction phase is oriented to producing the building itself.

The planning and design phase can be represented by means of Figure 2.1

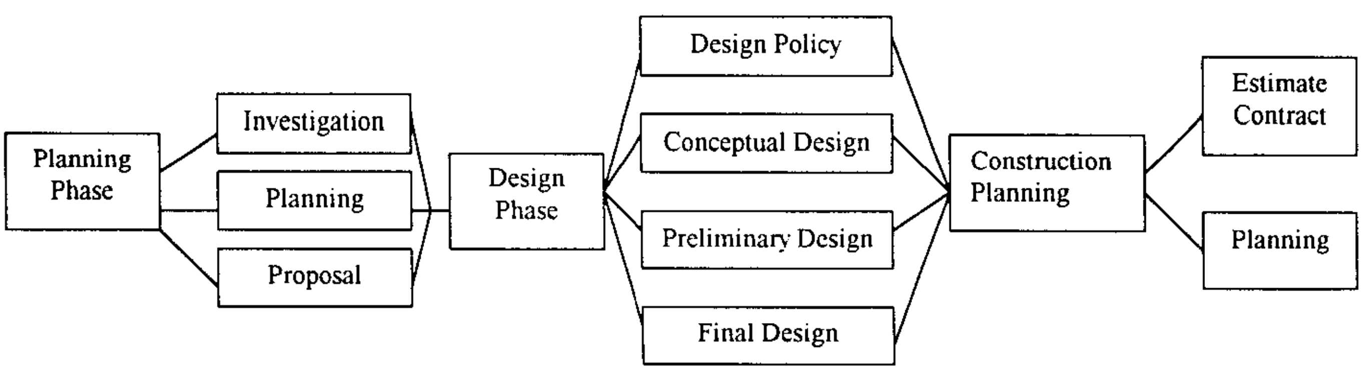

Fig. 2.1. Planning and Design Phase as a Function of Time.

2.2.1 Coordination Between Producer and Designer

For the introduction of information and automation technology in the construction industry, the first element that is necessary to analyze is the coordination between producer and designer. As was stated in the previous Chapter, it is desirable to increase, as much as possible, the share of construction work that can be performed at an off-site facility.

The following material, related to the pre-fabrication process, is extracted from "Industrialization and Robotics in Buildings". [2]. The economy of pre-fabrication, for any building project, may be enhanced by an effective coordination between designer and producer. The basic communication alternatives between these two participants are:

1 Production is based on the architect's design, with little or no regard to the pre-caster's consideration.

2 Production is based on the pre-caster's own design, for a general or a specific type of project, in most cases made to suit the requirements of a certain group of clients.

3 Production is based on a design that observes some general coordination rules, with respect to dimensions and location of elements. Pre-casters adapt the production of elements to the same rules.

4 Production is based on a design prepared by the client and following some common rules that ensures its adaptation to the particular producer's component system.

1) <u>Production based exclusively on architect's design.</u>

This implies a high cost in detailed design of components, adjustment of molds, etc. that can be only justified by a large enough production series for each element.
If the design disregards the specific constraints of the eventual pre-caster, the project may put pre-fabrication at an initial disadvantage with respect to conventional methods.

2) <u>Production based on pre-caster's design.</u>

This means a closed pre-fabricated system and the main problem will be the demand. If it can attract a big number of orders over a long enough time period, it can be economically successful.
This type of construction has been applied in countries where centralized planning could adapt the system to prevailing explicit norms and assure its universal use.

3) <u>Dimensional Coordination.</u>

Two possibilities of communication between an architect (on behalf of the client) and a producer of precast elements have been discussed on previous sections.

In view of the limitations of the former approaches, it is logical to think of a method that satisfies the needs of both the designer and the pre-caster. This system may be thought as an "open system" (this refers to the interchangeability of components of different products and technologies) of interchangeable elements, which could be supplied by different producers and could be used in any type of design conforming to the basic rules. The objectives of the modular coordination are to:

- Reduce the variability of the dimensions of building components.

- Allow for easy adaptation of pre-fabricated components to any layout and for their interchangeability with the building. For an open system design, it is necessary to clearly define the permitted deviation rate or tolerance for the production.

A clear definition of the permitted deviation rate or tolerance for each element should be defined for both the production and erection processes. Assuming the possible deviations, eventually affecting the position of an element with respect to its control line, as statistically independent of each other and following a normal distribution within the limits of their tolerance, the standard deviation σ of the resulting position deviation is given by:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \cdots} \qquad (2.1)$$

where σ_1, σ_2, -- are the standard deviations in the position of an element due to the effect of each pertinent factor independently of others.

There are five rules that can be accepted in the standardization process of the dimensional coordinator:

- The Controlling dimensions of horizontal components- *slabs, beams*, and *girders* – are limited to multiples of preferred multi-modules.

- The controlling dimensions of vertical envelope components – *exterior walls, columns, and cladding* – are limited to the preferred sizes of overall floor height or derived form preferred sizes for the interior height.

- The controlling dimensions of interior vertical components – *bearing walls and partitions* – are limited to the preferred dimensions for overall height.

- The *thickness* of walls, slabs, and the cross-section of beams and columns are limited to multiples of a basic module or preferred sub-modules.
- The controlling dimensions for *doors, windows, stairs,* and some other interior fixtures are limited by their preferred sizes.

There exist two main reasons that hinders the use if the "open system" concept:

- Differences in joints and connections.
- Non-modular and non-uniform thickness of key building components such as walls and floor slabs.

These difficulties could be overcome by a nationwide or worldwide introduction of a true open system.

Another concept is the integration of the concepts of closed and open systems in an "open-closed" or "flexible" system. This is a closed system in a sense that it employs a finite set of components produced, erected, and connected in a specific method. The system, however, conforms to general requirements of modular coordination and is devised in such a way that it leaves an architect with considerable freedom of design. These ends are attained by a selection of appropriate design multi-modules, which on the other hand considerably restrict the number of variants of main components - floors, slabs, interior and exterior walls – and on the other hand, allow generation of a maximum number of useful layouts of a desired type. The development of a flexible system involves a choice of components to be employed in the system and their sizes. A systematic design method, which was developed by the SAR (Stichting Architecten Research) Group is described in the cited reference for this part, and can be used for selection and evaluation of design modules in many types of residential and other buildings.

2.2.2. Coordination During the Construction Process

For the introduction of information and automated technology in the whole process, it is mandatory to have explicitly defined all the tasks and relations in the construction process. Figure 2.2 represents the different parts in which the construction process may be divided [1].

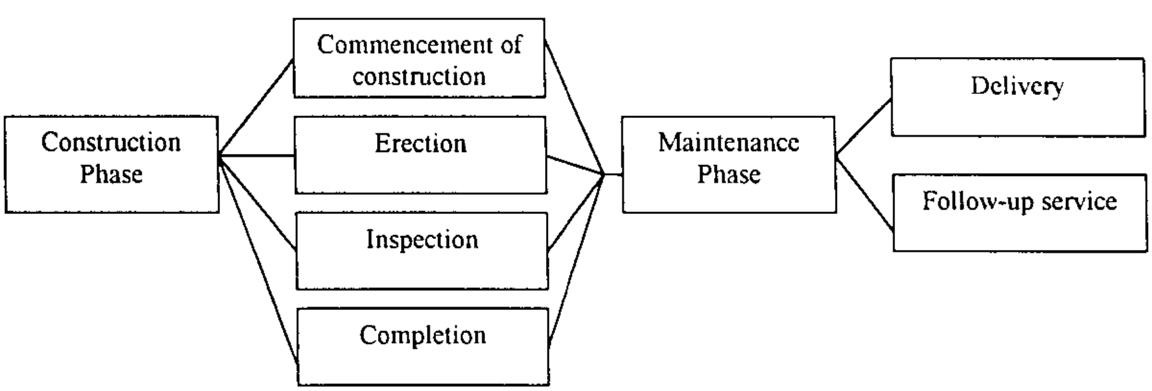

Fig. 2.2. The Construction Process.

As was stated by several authors, the central problem of coordination arises from the fact that the basic relationship between the parties to a construction project has the character of an interdependent autonomy. *There is a lack of match between the technical interdependence of the work and the organizational independence of those who control the work.*

A high number of coordination of activities exists, which construction project managers cannot always identify. These activities are numerous and miscellaneous in nature. They neither could identify specific customers nor specific inputs/outputs of their processes and claimed that the customers of a construction project manager are so numerous because he (she) has to work with every participant of the project and every outsider connected with the project, each having unique needs. It may be that the informal character and intangibility of construction coordination have made it very difficult for the practitioners to establish a model of the process itself.

An attempt to present the problem in a mathematical form [1] is obtained dividing the building or facility into conceivable parts (work sections) or activities (A) resulting in finished elements (D) these activities require resources (R) of different kinds.

Resources (products, human effort, etc.) are handled and refined on the site throughout a large number of systematic activities. The combination of a set of resources and an activity produces a finished element. The total result, the building, is presented as the sum of all finished elements:

$$\text{Finished Element} \longleftarrow \text{Activity (Resources)}$$

$$D \leftarrow A(R) \qquad (2.2)$$

Where $\leftarrow$ indicates an assignment and its direction.
The final result of manufacturing, P, the complete building is

$$P = \sum_{i=1}^{n} D_i \leftarrow \sum_{i=1}^{n} A_i (R_i) \qquad (2.3)$$

Where D_i is the i^{th} finished element.
A_i is the i^{th} activity
R_i is resources pertaining to A_i
n is the number of parts in which the construction project is divided.

Including the relationships among the different parts, it is possible to define C as a complimentary product or function and the building product will be expressed by

$$P = \sum_{i=1}^{n} D_i - \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} \ (i \neq j), \qquad (2.3)$$

Where Cij is the influence of the i^{th} element on the j^{th} element , a relationship that must be in order, otherwise the building P cannot be accepted.

2.3. Product Modeling for the Building and Construction Industry.

A goal of current research is to develop one or more computer representations of building information that can supplant all the current documentation now residing on paper. This information ranges from drawings, written specifications, spreadsheets, databases, etc.

"The potential benefits of modeling the building information include the improvement of information availability, supporting an open-ended set of further analyses and applications, reducing the space and time to store and transmit information, and at the same time to expand the base of information" [3]. Whole electronic communications for sharing and storing project information is currently difficult, if not impossible. Consequently, all participants in a specific project are required to convert computer- generated, electronic information into paper-based output.

The building and construction industry requires a complete and adequate electronic project information system. One of the tasks for the completion of this goal is the creation of standards, but if standards are not adopted by a significant number of users, it does not solve many problems. ISO 10303 STEP is a real intent of solving the problem. "STEP allows companies to effectively exchange information with their worldwide partners, customers and suppliers, as well as internally." [5].

STEP is an acronym, which stands for the Standard for the Exchange of Product model data. It is part of the International Organization for Standardization (ISO). It was developed by ISO TC 184/SC4 (Industrial Data). According to Fritz P. Tolman [4], "The coming years will show that STEP is using outdated technology that will prove to be ineffective for the building and construction industry. ISO is not the optimum organization to steer the pre-standardization process and there is not even a consensus among the researchers that are carrying out the efforts". From this, one can see that everybody does not support the use of the ISO standard. Only in the future will the decision to take become clear.

The other alternative also presented in the same work is to abandon the development of standards but solve the problem by providing a service. OMG (www.corba.com) allows a service provider to assist the participants of a building and construction project in setting up a dedicated and distributed project database. The OMG was formed to create a component-based software marketplace by hastening the introduction of standardized object software. The organization's charter includes the establishment of industry guidelines and detailed object management specifications to provide a common framework for application development. Conformance to these specifications will make it possible to develop a heterogeneous computing environment across all major hardware platforms and operating systems. Implementations of OMG's specifications can be found on many operating systems across the world today. OMG's series of specifications detail the necessary standard interfaces for Distributed Object Computing. Its widely popular Internet protocol IIOP (Internet Inter- ORB Protocol) is being used as the infrastructure for technology companies like Netscape, Oracle, Sun, IBM and hundreds of others. These specifications are used worldwide to develop and deploy distributed applications for vertical markets, including Manufacturing, Finance, Telecoms, Electronic Commerce, Real-time Systems, and Health Care.

Another example for the use of INTERNET in the construction industry is the effort done by Bentley Systems, Inc. launching Viecon.com Project Extranet [17]. The project is focused on maximizing the effectiveness of Engineering, Construction and Operations (E/C/O) networks by allowing members of project teams to create, communicate and collaborate efficiently over the Internet. "It provides a real-time, interactive environment for comprehensive, project life cycle management of all the tasks and documents associated with a project. In use, you can create and manage projects with a comprehensive suite of scheduling, tracking, meeting, and calendar-based software. Meetings may be physical (in a single site), teleconference, or on-line, interactive, where the host's screen is visible to all participants. In addition, there are downloadable tools for viewing drawings, sending drawings over the web as emails, and a conversion tool for maintaining data for DGN, DWG, and DXF formats."

In order to use effectively these tools, it is mandatory to have general concepts about building models, life cycle and the necessary information needed on each stage of the construction process.

For any building it is possible to define five stages [3]:

1) Feasibility study
2) Design
3) Construction planning
4) Construction
5) Operation

The feasibility study is the generator of the building model and thus influences the design and later stages. This stage also plans and set goals, at a general level, for all the other stages. This stage defines the purposes of the building project and assesses if the resources are appropriately matched with the project scope. At this stage, the costs are balanced with the function of the building. The planning at this stage of the building model often involves developing many different feasibility models and comparing them in different dimensions. The following four tables are reproduced from the same paper. Table 2.2 presents the different parameters to take into account and the type of data necessary for this stage.

Table 2.2 (Source Eastman, 1993).
Applications and Data to be Supported During the Building Feasibility Stage.

PARAMETERS	TYPE OF DATA
total units, rental or usable space in terms of functional service provided	building quantities and qualities
project schedules, form conception to operation other time-based models of planning, design, and construction	time
project costs: design, construction, license, and bonds	money
operating costs: amortization, utility, and other operating costs	money
cash flows	money
market absorption models	building quantities over time
material and labor quantity availability	units of labor and materials over time

The design involves the translation of functional criteria developed in the feasibility models into detailed descriptions of the building project to allow fabrication and process planning. Design also involves assessing that the facility will achieve its intended functions. Table 2.3 shows the different activities and the type of data necessary in this stage.

Table 2.3. (Source: Eastman, 1993)
Applications and Data to be Supported During the Building Design Stage.

TASKS	TYPE OF DATA
CAD systems, defining geometric layout and all materials	geometry, material properties
analyses of design in terms of:	
-construction costs	money
-structural safety	material performance units
-energy costs for heating	
-vibration, other special performance dimensions	
simulation models showing building behavior in terms of:	
-lighting simulation	lighting units
-acoustic simulation	reverberation time
-people and traffic flows	human densities, speed
-mechanical system operation	energy units
-elevators and transport systems	time
automatic design and detailing for:	
-standard design situations	geometry and materials
-standard detailing conditions	
-particular stylistic intentions	
expert system support, for example advising on:	
-energy efficient design	geometry and materials
-material and part selection	knowledge base of
-operating and maintenance issues	technical information in
-construction guidance	various areas
-water and moisture	
building code evaluation, for such issues as:	
-fire safety	geometry, use data
-structural safety	material data,
-earthquake safety	energy and movement
-access for handicapped	
-habitability, fresh air and light	
site development, in terms of:	
-grading	site contours
-road, walkways, planters and landscaping	groundcover
water and drainage systems	soil types
-wind simulation	wind conditions

The construction-planning phase involves the bidding and tendency processes that develop a construction plan and estimated construction costs. Empirically divided databases are very important in this stage, for dealing with materials and labor costs.

These units of work and material are the basis for cost estimates and later procurements and scheduling. Detailed investigation of the construction site is carried out at this stage, including borings and geological investigations. Table 2.4 shows tasks and type of data necessary in this stage.

Table 2.4 (Source: Eastman, 1993)
Applications to be Supported During the Construction Planning Stage.

TASKS	TYPE OF DATA
CAD system description, defining geometric layout and all materials	geometry, material properties
construction task planning: -determination of in-place material quantities -association of units of work w/ units of in-place material	material units time and work crews
detail product specifications	
site investigation: -soil and stone boring	locational data, soil and geological coding
geological studies	
temporary construction layout planning: -scaffolding and shoring design -site layout use and scheduling	geometry and materials properties, site locations, time
regional resource planning for large projects: -production capacities for local materials -availability of regional labor pools -acquisition plans to deal with shortages	material or work units over time

The construction stage executes the construction plan. In the future, it is possible to expect that each subcontractor will receive a design model of the building component, from which they will define both a detailed fabrication design and a process schedule for their components, for both on - and off - site work.

Table 2.5 shows the tasks involved in this stage, and the necessary type of data.

Table 2.5. (Source Eastman, 1993).
Applications to be Supported During the Construction Stage.

TASKS	TYPE OF DATA
CAD system description, defining geometric layout and all materials	geometry, material properties
-PO procurement scheduling and tracking -inventory management	POs, dates, actions
detail construction task planning -detail layout planning: -interference checking -assembly simulation	geometry, material properties
-task breakdown and sequencing	tasks, time
-heavy equipment leasing and /or scheduling	equipment, time
-job scheduling, tracking and status reporting	
-work crew assignment	people, time
surveying and geodesy for construction layout	3-D geometry
custom drawing for production crews	geometry, process plans, materials
temporary construction: -scaffolding and shoring	geometry, materials
as-built documentation	geometry, materials

2.5. Conclusions

1. To be able to integrate the construction process, it is mandatory the use of models for representing the different participants in the construction process and standards to exchange the models' data.

2. A way of solving the differences between designers and pre-casters is the creation of open systems of interchangeable elements, which could be supplied by different producers and could be used in any type of design conforming to the basic rules.

3. There exist two tendencies in the product modeling in the construction industry. One is the creation of standards like ISO 10303 STEP, and the other is to use companies that provide this service like the OMG.

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CHAPTER III

NEW COMPUTER-BASED RELATIONS IN THE CONSTRUCTION INDUSTRY.

3.1. Introduction

The construction industry was estimated to be a $300 billion industry in the United States in 1983. That number is probably closer to $500 billion today, yet the industry consistently has shown declining productivity, especially when compared to other US industries. Both the National Research Council and the National Scientific Foundation have recognized this problem and sponsored research to define methods for improving the integration of construction through the use of computers.

With the introduction of computers and computer applications, a big quantity of information has been generated, related to projects, company, and in general with all of the construction process. Unfortunately, because communications between project participants has not been developed at the same trend, islands of knowledge and information have resulted.

Since computers increasingly and successfully support design and construction, it only seems logical to support their communication with computers also. [9].

With the construction integration process, suppliers have a growing influence on the design, which results in designs that better fit the construction needs. This process has been defined as the continuous and interdisciplinary sharing of goals, knowledge, and information among all project participants.

The general means used for solving tasks in the construction industry are not suitable for open-systems communications and it is necessary to introduce software permitting this high-level computer communication. This will be possible when the reasoning behind the design and construction choices is made explicit in communication. To realize this, application needs information with more explicitly defined meaning, which is related with information at a higher semantic level.

As stated by Yukio Hasegawa [27], "the recent efforts of rationalizing the industry reached the point to integrate planning, design, fabricating, and assembly process like manufacturing industry." The previous separated design information and construction process planning are combined and integrated as a big construction system. That conceptual progress is considered by Hasegawa as the trigger of construction automation.

To achieve the consolidation period in the construction automation, it is necessary to focus the efforts in four main directions [28]:

1. *Integration:* Focusing on feedback design of houses, the use of high number of the same standard pre-fabricated elements and software standardization.

2. *Pre-fabrication:* Increasing the mass production pre-fabrication in order to select the parts from a catalog, and at the same time focus on the standardization of the maximum number of parts through the use of grid dimensions, common joints, connections, etc. At the same time the creation of new materials for pre-fabricated parts, which make them lighter, maintaining the same mechanical features.

3. *Robots and Automated Machines:* Focusing on the creation of "easy" to use and cheap robots, and at the same time increasing the level of automation of existing machinery.

4. *More Investment:* Increasing the level of investment in these new techniques in aspects as education, changing the culture of operators directly involved in the construction process, and promoting more R & D programs for construction automation.

3.2. Architect/Engineer/Contractor (AEC) use of Automated Information Technology.

The following are several practical applications of Information Technology (IT), covering the use of computers in construction from an integrated point of view, as well as automation and robotics. The material was fully extracted from the cited references.

3.2.1. The SMART System [11]

Construction companies in Japan are under intense competitive pressure. Major changes are expected with respect to construction processes, products, organizations, resources, markets, methods, and technological strategies. The construction companies are thus faced with the need to optimize the way in which they function in order to achieve the best possible performance with constraints.

The SMART system is an integrated automated construction system, which automates a wide range of construction procedures, including the erection and welding of steel frames; the placement of pre-cast concrete floor planks, exterior and interior wall panels, and installation of various units. The system utilizes pre-fabricated components extensively. In addition, the assembly process is orchestrated by real-time computer control, resulting in construction site operation in a highly automated way.

Lifting mechanisms, automatic conveying equipment and steel-frame welding constitutes the heart of the SMART system. The system was applied to the construction of the Nagoya Joroku Bank Building. This is a 20-story, above ground, and two more underground building. The total floor space measures 20,000 m^2. Table 3.1 shows the labor reduction in structural and finishing works.

Table 3.1. Labor Reduction in Structural and Finishing Works.

Construction	Reduction (%)
Steel frame erection	43
Steel frame welding	45
Installation of exterior walls	62
Installation of pre-cast slabs	50
Installation of interior walls	43
Plumbing (main)	67
Electric (main)	90
Total (including other works)	30

The automated construction sub-systems are the lift-up and automatic welding systems. The information management system is composed of the real-time monitoring system, the production information management system, and the process information management system, which is focused to the control of resources at site.

The effects due to the introduction of the SMART system can be summarized as follows:

1) Through all-weather protection
2) Workers have been freed from operations with heavy workloads.
3) The labor man-hour is reduced by about 30%
4) Safety at work has been drastically enhanced.
5) The workload on-site management personnel have been greatly lightened.
6) Construction wastes were reduced by about 70%.

3.2.2. Application of Automated Building Construction system for High-Rise Office Building [29].

High-rise steel structures are usually built using tower cranes. The quality and progress of work executed by this method can be easily affected by weather conditions. The need to work at elevated levels is another problem, and the aging of construction workers and a shortage of skilled workers are aggravating problems. The Automated Building Construction System (ABCS) is a new construction system developed to solve these problems and at the same time increase productivity.

The constructed building is a 26-floor building with 2 basement and two penthouse floors. The maximum height is 110 m. and the total floor area 79,752 m^2. The principal components of the ABCS are a structure that encloses the working space, and a parallel delivery system.

The ABCS integrated management system consists of three subsystems: The production management system, the equipment operation management system, and the machine control system.

The production management system converts design CAD data to construction models, and performs scheduling and performance management of the delivery and installation of materials. The equipment operation management system supports the automatic operation of the "Super construction factory (SCF)" cranes. The machine control system controls the operation of the climbing system. In the project all the SCF crane operations and the welding of steel columns by welding robots, were automated.

The unit labor requirements for the ABCS-based construction were 61% of those of a conventional construction. According to the accumulated data, the time required for performing the same tasks became shorter by more than 10%.

3.2.3. Polshek Partnership's Rose Center. [30]

In this project, Polshek used computers to design interactively with engineers. To better understand geometry and fabrication issues, architects created an independent 3-D AutoCAD model, which helped in determining construction methods. The fabricator team coordinated with the designers via E-mail. Some specialized components, such as stainless-steel spider casting and rod riggings that secure the Rose's center glass skin to its structural frame, were first modeled in a 3-D mechanical design software, and transmitted via E-mail for fabrication.

To test the air distribution scheme developed by the mechanical consultants, the numbers were cranked through a computer modeling technique called computational fluid dynamics. This method enabled the architects and mechanical consultants to reach agreement on the correct airflow design.

During the six-year project, Polshek upgraded its Micro station CAD software three times; went through three generations of desktop PC's; upgraded its network infrastructure and converted from Netware to Windows NT; implemented a new E-mail system; evolved its system for drawing standards and setup; and changed network administrators and CAD managers twice. All system, files, and formats had to be coordinated across multiple generations and often-incompatible versions.

What advantages were obtained?

- The casting design could not have been done without computers.
- The collaboration among the participants could not have been done without computer modeling and communications.

- The computer analysis enabled the client to understand what the space could look like.

3.2.4. The ARMILLA Project [12].

The paper provides an overview of the research and development of ARMILLA from 1989 to 1999. ARMILLA describes a variety of different CAAD research projects at the Institute for Industrial Building Production (IFIB) at the University of Karlsruhe.

ARMILLA 1 was finished in 1986. It follows the idea of "design automation". The system demonstrated that the implementation of the ARMILLA model as a computer aided design tool based on objects and rules is possible.

ARMILLA 2 was implemented with Knowledge Craft as a blackboard system with a simple-to-use, CAD-like, user interface. A particular emphasis of ARMILLA 2 was the design of an effective dialogue between user and expert systems on several levels of abstraction.

ARMILLA 3 combined the object-oriented database ontos with Auto CAD for a multi-user design environment.

In ARMILLA 4 prototype, the research field was expanded from construction tasks to building management. The user can enter a building remotely and get an introduction to it with multimedia techniques. The user can "move" through the building and make use of various services.

The ARMILLA 5 prototype generalizes the ideas from ARMILLA 4: the spatial cooperation and communication between data, tools, and designers within a multidimensional design space, and sums them up under the metaphor of a "virtual construction site".

ARMILLA 5 distinguishes between three different classes of virtual building components: plain data, simple standalone functionality, and complex functionality based on client-server models.

ARMILLA 6 follows the idea of a parallel world of virtual construction sites and dynamic buildings. Special projection techniques can be used, which can integrate the virtual building components into the real building homogeneously and ergonomically.

3.2.5. Robotic Bridge Maintenance System [13].

Robotic systems for construction applications have advanced dramatically over the past few years. Automated systems were initially developed to reduce labor requirements, shorten construction time, reduce costs, and improve quality. Currently, benefits as moving workers out of the dangerous work areas have improved the worker's environments and improved worker morale.

The robotic bridge maintenance system has four main capabilities: remote inspection, spray washing, paint removal, and painting. The basic goal for the system is to eliminate the need for a human to be involved directly in the removal process and to contain the lead-based paint.

One of the major advantages that this system has over others is that it has been designed as a relatively simple modification to existing equipment. Another advantage is that the robot can be used for other types of applications in which a tool needs to be manipulated and it is desirable to place the worker at a safe distance.

3.2.6. Strategic Use of IT in Some European Construction Firms [14].

Kingdom Ltd.'s main business area is building and housing, roads, and civil engineering. The main incentive to invest in IT was earlier rationalization but the importance of cost reduction has decreased over the years. The focus has shifted towards quality and quality assurance. The use of IT on the construction site includes applications for planning, estimating, and project management. Also, in large projects there is a direct communications between the site and the server of the main office. The client has access to information concerning the project. Through this access he/she can follow the project on a day-to-day basis.

Baumeister AG is a management contracting firm and acts as a coordinator between the client and the other firms or subcontractors involved in construction projects. The firm's main competitive edge lies in efficient management of construction projects on a fee basis. Baumeister AG's main reasons for investing in IT lies in improving efficiency, adding more value to the client, reducing costs and ultimately increasing market share and barriers to entry.

The firm's objective is to lower the barriers to entry for new suppliers such as architects, consultants, quantity surveyors, and subcontractors that want to enter the network and perform specific tasks in the projects.

Construct Ltd. is an international firm with large experience in international construction. The main international market is in civil engineering: roads, bridges, tunnels, dams, and sewage water treatment plants. The competitors in the international market are primarily Turkish, Egyptian, Korean, and Chinese firms. The competitive edge of these firms lies in the lower costs of labor. Since the competitors have this advantage Construct Ltd. has to define a different strategy to meet the fight.

The firm has chosen a "differentiation-focus" strategy concentrating technologically complex projects, which require large experience to produce. The opinion of the firm is that IT is a key technology in enabling differentiation.

3.2.7. ICATECT II [15]

Icatect-II is an approach together with a set of tools, that permits the development of integrated building design environments which allow building data to be shared between multiple tools, and multiple building design professionals.

To solve the problem of data sharing, it has created a central Integrated Data Model (IDM) describing all of the relevant data needed for a building. Users utilize their design tools (DT) to accomplish certain design tasks, the results of which are passed into the integrated design system and merged with data stores in the IDM. Conflicts between the data from various users are detected and the affected users negotiate compromises to their problems. The control system monitors the problems and resolutions, and, dependent upon the results determines the next set of available design tasks for the attached users.

The conceptual model that is required for completely specifying building design information is perhaps the largest and most complex information model under active development to date. A primary focus of this work has been the development of the ISO STEP standard.

Having developed the design tools, schemas, mapping, and design tool interfaces, tools are required to both create model instances and to move data between them according to the mappings.

3.2.8. Plan of Construction Automation – Building Engineering Automation [26].

A 10-year plan has been prepared in Taiwan to realize industrial automation. Since 1990, the plan is taking place in areas as selected manufacture, commerce, agriculture, and construction industry. During the performance of the plan, the construction automation has been divided into civil engineering and building industry. Architecture and Building Research institute (ABRI) of Ministry of Interior takes the responsibility for the building engineering automation.

The objectives of the project are: increase the productivity in construction, improving construction quality, shortening work schedules, lowering down construction costs, promoting construction security, improving working environment, reducing disaster at the job site, overcoming the shortage of labor force, reducing construction materials, reducing construction pollution, promoting environmental quality, and providing more comfortable and secure living space through the intelligent building management.

The research topics studied over the decade are:

- Promotion and application of building engineering automation technique
- Promotion and application of information systems of building engineering automation technique
- Consulting service of building engineering automation technique.

3.2.9. New Developments in the US

Several big construction companies in the US are implementing IT applications. As examples may be cited:

- *Betchel, Black & Veatch*, and *Gilbane Building* began in 1999 a fast track deployment of online collaboration and project management tools that could shorten cycle times for design and building projects [31].
- The city of San Francisco is using BidCom's process management applications for a recent public work project. Instead of taking notes on paper in the field, city inspectors use handheld information to enter survey results into the BidCom system, eliminating redundant data entry when they go back to the construction trailers [32].

As can be seen from the presented examples, there exists a wide tendency towards the integration of diverse managerial functions: engineering, contract administration, quality control, accounting, commercial transactions, and reporting. Unfortunately, no satisfactory general solution has emerged so far due to the complexity of the interactions and the differences in the methods used by diverse groups on different projects. At this moment, one of the effects of IT has been to fragment the construction industry, because different organizations are at different stages of IT implementation and simply will not "talk" to each other. The reason is that the software architecture has thus far been designed in an ad hoc fashion primarily to perform individual business functions, such as scheduling, cost estimation, purchasing, inventory management, or financial accounting. In many construction companies such function-oriented applications gave rise to an unmanageable maze of system components, and data could not be easily transmitted to other partners. For solving this situation, interfaces have to be developed to link the various applications. This problem becomes more complicated by the fact that, once instituted, function-oriented structures could not be transformed into process-oriented structures; as a result, companies sacrificed flexibility and the ability to introduce changes. This phenomenon, which is characterized by a high degree of internal integration with very loose or non-existent connections, is called "islands of automation". [33].

Among the changes that IT has introduced in the traditional relationships between designers and constructors is the possibility of working like a team, which has the ability to communicate faster, so decisions can be made quickly. It is difficult to estimate what represent for a contractor to have a piece of information today versus tomorrow. Figure 3.1 shows the traditional relationships between owner-designer-contractor. Now that most construction firms are relying on computers and communication technology to perform office functions and project work, these systems are influencing how the different parties in the construction process work together. "The connectivity afforded by digital tools makes possible new levels of coordination and management control in single-project associations, more formal joint ventures, and permanent partnership created by mergers or acquisitions" [48].

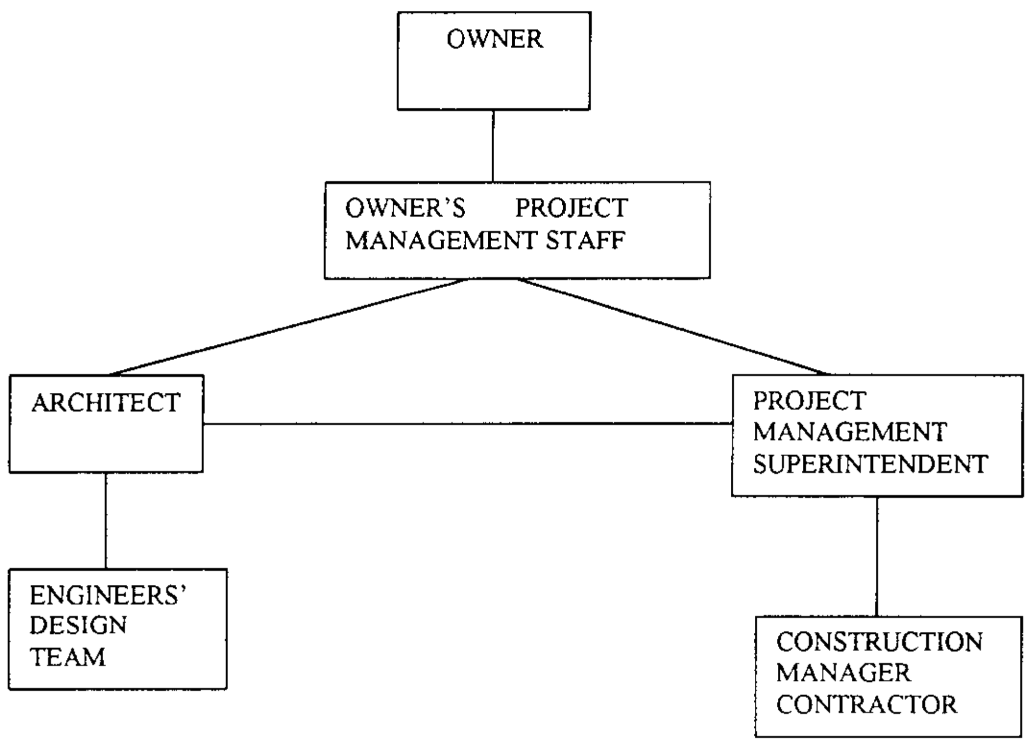

Figure 3.1. Owner-Designer-Contractor Relationships Representation.

The basic change with the new technology is that the process can be changed interactively and accordingly to the needs. In other words, the feedback is made more efficient. It is very important for the different parties to sit down at the early stages of the project and work trough all the issues, like setting which office standards will apply to the project documents.

It becomes clear that collaboration across multiple project phases pose greater technological complexities, more file translations, and additional coordination issues. The best course to follow, according to Tim Rice, information system manager at LMN Architects in Seattle, is to decide, "Which firm will own which drawings during which phases. This means that each firm will spend some additional time and money redrawing in its own files those changes made by the other firm".

The Jerde Partnership International in Venice, California, has developed a process of two-way workflow that they call Construction Document Administration. It is based on all participants matching the same tools: Microsoft Office, AutoCAD, 3-d studio, Internet compatible E-mail, and file transfer protocol (FTP). The entire team needs to have comprehensive, universal standards that are flexible enough for all team members to participate. Another significant coordination issue is keeping the team's software in synch throughout a multiyear project development cycle.

In the near future it is expected that rather than cutting procurement costs by putting pressure on their suppliers, construction companies' IT departments must devote resources to integrate CAD, enterprise resource planning, project scheduling, and other systems to reduce job-cycle [32].

3.3. Future Applications of Information Technology (IT)

A recently completed survey of construction industry CEOs about their companies' information technology use and investments patterns indicates they are typically expending from 1% to 4% of revenues on IT investments. Historically the process of designing, constructing and operating buildings is among the least computerized of all industries. The situation is changing with the use of sophisticated new methods and software. Now the concepts of Artificial Intelligence models, computer integrated construction, and Internet are increasingly being used in the construction industry. The main goal is to create an environment in which computer programs can share and exchange data automatically, without translation of human intervention, starting from the building design and finishing with its operation, or may be until its demolition. In this study, the state of the art of the mentioned related areas that converge to achievement of the main goal will be presented.

3.3.1. Artificial Intelligence Models

The research area of Artificial Intelligence (AI) has been performed mostly by a small number of most important Universities and research labs. In the recent years, AI &Expert Systems have received enormous exposure. The lower hardware price and the accessibility of dependable and supported software tools have allowed AI to come into view as a practical technique that presented a large selection of constructive applications in manufacturing and engineering fields.

Artificial Intelligence may be applied in just about all-major areas of manufacturing, particularly those that rely on practice and know –how (e.g., process planning). Several probable errands could incorporate the subsequent areas [34]

- Design of Mold, dies, and runners in casting and injection molding
- Selection of tool materials, feeds, and speeds of cut in metal processing
- Generative process planning
- Assembly planning

- Factory Management
- Cost Estimation and Budgeting

Expert systems produce intelligent behavior by operating on the knowledge of a human expert in a well-defined application domain. These Expert systems include a knowledge base containing information, set of laws and condition patterns, and an implication system that makes assessment with in a field. Modern applications of expert systems have established the prospect to attain a lofty point of individual piece with preserving information that otherwise might be gone by abrasion, withdrawal or, death. These systems also have established the ability to advance the performance of standard individuals by providing them access to the encoded understanding of the limited specialist.

The expert systems' tasks are **1) Interpretation 2) Diagnosis 3) Planning 4) Monitoring 5) Prediction 6) Design.**

A design project is commenced with a set of necessities produced by the sales/marketing strength for the product design group (engineering/manufacturing). These requirements are converted into ideas about things; which in spin are decoded into engineering treatment for converting appropriate resources into constructive physical objects. The design method commences with the theoretical work, continues with viability study and preliminary design activities, and is finished with completed design and manufacturing engineering processes, which are used to prepare the production plan. Interested readers can view the total design process in the paper " Faith Kingly, Don Riley, "Expert system model of the design process" Conference Autofact '85 November 4-7,1985"

There are several building computer model. Among them can be cited: RATAS, CUBE, COMBINE, ATLAS, and CAFÉ. A more complete description of these models can be found on appendix A.

3.3.2. Computer Integrated Construction [7]

Computer Integrated Construction (CIC) is a concept, which has yet to be fully realized in the US construction industry. Its goal is computerized data collection and integrated information flow between planning, design, construction, operations and business functions for optimizing the performance of the entire organization. Today, computer applications are being applied to almost every facet of the construction business. Computers are used during the concept and feasibility study stage. Various simulation programs can facilitate the "what if" scenarios that are critical to the feasibility study. During the design stages, structural analysis and CAD programs have proven invaluable tools. The project managers and cost engineers make good use of cost estimating and project planning software such as Timberline's Precision Estimating package and Primavera's P^3, during both the planning and construction phases. The accounting departments are fully computerized to handle payroll, billing, purchasing, and contract management functions. Finally, using various building maintenance and energy management packages can enhance the long-term operation of the facility. Despite the sophistication of these information systems, they have a significant shortcoming. Each was originally designed as a stand-alone system and they have little ability to communicate with each other. Information, which resides in the designer's CAD system, is not easily transferable to the cost estimator, at least not in a form that he would find usable. Likewise, changes to the price of material, which are known to the purchasing department, do not automatically flow to the cost engineer and project manager. They must be passed along and manually input to their systems. A completely integrated construction system would allow this data to transfer freely between the different applications. More importantly, it would allow all the participants to have that new information at the same time. This may seem to be a very large task, but there is a precedent for it.

Computer Integrated Manufacturing (CIM), which has goals almost identical to CIC, has a ten to fifteen year head start on the construction industry. The manufacturing industry adopted CIM for the following reasons: to reduce costs, achieve better quality, improve customer service, allow greater flexibility responding to customer requirements, and reduce time to market with new products. Both productivity and quality have shown significant and steady improvement in the manufacturing industry over the past twenty years. Since the construction and manufacturing industries share more common ground than differences, it would be prudent to closely examine the progress in CIM. Many of the developments in CIM should transfer directly to the construction industry. Where we have pronounced differences, there are two options.: It may be necessary to modify the integration techniques to match our unique needs or it may be more advantageous to change the way we do business. As an example, in manufacturing, the designers, the engineers, and the fabrication specialists all work for, or are captive subcontractors of, the same company. We will probably never have this exact situation in construction, but in private construction, where the contacts are not awarded by bid, it is possible to select a contractor early in the design process. Then the designers, the project manager, and the key subcontractors can be brought together to collaborate and avoid costly design errors. Additionally, manufacturers learned that it is necessary to maintain close and long-term relationships with suppliers and subcontractors. The large companies dictate the quality and performance standards and in return they guarantee to use those suppliers and subcontractors. Instead of the adversarial relationship, which is common in the construction business, the manufacturing subcontractors view the success of General Motors or Toyota as important to their success. That would be a major paradigm shift for the construction industry, but it's worth thinking about. However, since the construction industry will continue to operate, for the most part, as a coalition of different business coming together for a single project, the only solution to implementing CIC will be for the industry to adopt a standard architecture for computer information systems.

One area where manufacturing and construction are very different is in the interface between designer and constructors. In manufacturing, there is a new discipline for manufacturing engineers. These are usually mechanical and electrical engineers with training in both design and manufacturing. They not only work on a new product at the concept and design stages, but also carry it forward through production. Consequently, the design process is heavily oriented toward optimizing the production cycle. Even with this philosophy, the most difficulty in computer integration has been at the break between design and production. Because of the difference in databases and the knowledge involved in the two processes, it has been difficult to integrate these processes. In construction, where the designers and the constructors work for different companies, this process will be more difficult. Again, the need for an industry standard is compelling.

According to Sanvido [5], "integration of a process requires a common set of standards and definitions acceptable to all participants, i.e., a model". Major work in the modeling of manufacturing processes was done in 1983, with the introduction of the Air Force integrated computer-aided manufacturing (ICAM) program. These models have been refined since that time and the construction industry is working on integrated building process models, which build on the work done by the manufacturing industry. The development of appropriate and comprehensive models of the construction processes is the most difficult and challenging of the tasks required to fully integrate the construction process.

The industry continues to struggle with these concepts, but a review of the recent literature is encouraging. An article, "Into the Fourth Dimension" appeared in the May 1999 issue of Civil Engineering [6]. It details the efforts and accomplishments of an owner-assembled team, which designed and built an addition for a pharmaceutical plant. The A/E firm, the general contractor and the mechanical, plumbing and electrical subcontractors were assembled early in the design stage. The team used and integrated design-cost-schedule approach to the project. The selected software suite integrated a 3D CAD program from Autodesk, Timberline Precision Estimating, and a scheduling software package called Schedule Simulator. All of the members of the design build team used this package and the subcontractors were actively involved in the design.

They reported that the design-cost integration was complicated and time consuming. Since no existing estimating database contained all the items necessary to complete the estimate, it was necessary to build one, which defined 314 items defined by subcontractors. Next, it was necessary to use formulas to convert these items into usable quantities, which could be extracted from the CAD drawings. These elements automatically linked with the CAD elements when the estimate was being created. The team reported a good start toward full integration of the design process, but they continued to have limitations. Some of these will be corrected by improvements in software, while others are process problems. For example, the way CAD objects were drawn did not always allow them to be associated with the individual schedule objects. Greater collaboration between the designer and builder was required to address these problems. Because of these efforts, the project experienced practically no rework on the ducting and piping. Only one change order was initiated on work designed using 3D CAD and requests for information were reduced by 60 percent.

Revit Technologies Corp. [8] is currently marketing a new parametric building modeler it claims will integrate real time design and changes throughout all of the construction documents. The software captures all relationships between design components and using advanced intelligent objects, the drawings contain attributes that tie into scheduling and costs. If this software works properly, the CAD model will provide the quantities necessary to develop preliminary budgets during the design phase.

The new technologies described above are bridging the last major gap in the integration process. Primavera, Meridian Project Systems and Timberline have already made great strides to integrate the post design phases of the construction process [3]. Primavera's Concentric Management System integrates Primavera Project Planner, with Expedition contract control software, Monte Carlo risk analysis software, and a WEB based communication project to allow all the project participants to get real time information from any location. The largest construction companies are already using these packages, but the technology is slow to filter down to the small and medium companies.

The last major hurdle will be to get designers and builders working as a team, as in the pharmaceutical company example mentioned earlier.

3.3.3. Future software Developments

The existing software packages differ at many levels, including how they name, subdivide, and classify building parts; the way they organize the attributes of those parts; and their method of linking parts and attributes. They also differ in the techniques they use to represent parts and attributes. The consequences of all this variation include lost or duplicated information, inaccurately transferred or converted files, and multiple databases of redundant information. Plus, much time and effort are wasted in checking these possible sources of error. Everyone would benefit if these communication problems were eliminated. Architects and engineers could incorporate better cost and schedule information into early design stages, sparing themselves some of the agonies of redesign. Those involved in the construction phase would enjoy faster project documentation and smoother workflow. Building owners and operators would benefit from more predictable time and cost estimates and would get a useful set of "as-built", along with other project information, when the job is done [35].

Future software systems should have the ability to exhaustively define a building through its entire life cycle. Vendors like Autodesk and Bentley systems suggest a single, unified data model that encompasses all the information about the building, from its initial programming through all the phases of design and construction. Also it will serve as an aid to maintenance and operation and even will cover the building's eventual demolition. As building evolves, the models grow richer in information added by architects, their consultants, and the constructors. This data will include the graphic representation of the building's form, numeric results of engineering analysis, text-based material specifications, project schedules, cost calculations, and more. The goal is to form a software bridge between mathematical coding- the language that computers read- and the characters and pictures that human can see and understand. This means to create appropriate "models" [36].

In the future it becomes necessary to move in the design, from the basic CAD software that produces 2-D drawings to advanced 3-D CAD software known as "virtual building". Computer models of buildings also can include the attributes of a building's components, like the density of the concrete or the fire rating of the partitions [35]. The industry CAD professionals move in three directions:

1. Creating and implementing CAD standards
2. Organizing and constructing CAD training programs
3. Integrating CAD with the Internet [37].

The International Alliance for Interoperability (IAI) has devoted most of his effort to building a consensus around a set of definitions and descriptions of all the elements of buildings and attributes of those elements. This is not a computer language, but something that logicians call a classification system for every aspect of design, construction, and building operation. This system is codified in a set of software standards called Industry Foundation Classes (IFC). Analysts estimate that widespread adoption of IFCs could cut by 70% the wasted effort in translating or duplicating data from one software model to another. The IFC uses the 3-D object-based CAD concept, which is quickly emerging as the new standard CAD rationale for the industry [38].

Internet appears like the ideal support for IFC. The problem is that the Structured Generalized Markup Language (HTML) used as main data interchange mechanism on the Web deals only with the format or appearance of the information, not with its meaning. Thus a standard Web site that uses HTML cannot determine whether a number is a quantity, date, a unit of measure, or a unit of currency. This situation may be solved with the use of the eXtensive Markup Language (XML), a way of extending HTML.

In 1999 the project aecXML was initiated for developing a subset of XML tailored to a content and meaning appropriate to AEC business. The main idea of aecXML is to not only establish some standard ways of structuring building data, but also to do it so as to enable automated processing of that data as much as practicable [39].

3.4. The Impact of INTERNET

In general the construction industry has lagged behind other industries in Internet applications. But this situation is changing. One of the possibilities that Internet brings to the users is that they don't need to be in a specific location. It is possible to access the resources anywhere there is a PC and Internet browser.

There exist many companies that act as "Application Service Providers (ASP)", allowing the costumer to access their software over the Internet for a monthly subscription fee at affordable prices [40]. A step further is the use of a "Management Service Provider

(MSP)", which manages Information Technology (IT) operations for multiple business, running and monitoring computer networks and software, hosting web sites, as well as providing web access and e-mail [41].

Among the benefits of using ASP and MSP are [42]:

1. Small and medium sized companies can compete with larger corporations without spending a lot of money or recruiting skilled IT personnel.
2. Using project management software on the web people can view the same page on the web with figures that are recalculated as they change, and the two parties can negotiate online.
3. All the software is integrated. So the backend accounting software, for example, is integrated into its project management software, both as a software product and online.
4. The union of scheduling to e-commerce permit, for example, tracking materials from the manufacturer to the job site.

Among the more representative online services can be cited:

1. *Online bid transmission services.* In the US several states are applying this method of bid submission. Others are in the process of implementation.
2. *Business-to-business Internet applications for the commercial construction industry.* Comprehensive multi-vendor e-marketplaces are replacing company-specific purchasing sites, providing users with a value-added virtual mall where they can quickly conduct searches; request bids, and compare product prices across suppliers [40].
3. *Automated Service Dispatching.* The user can receive customer request electronically, check crew schedules online, and dispatch the staff using a PC to send a message to the pagers or personal digital assistants. Also the crews can send job completion reports back to the dispatcher electronically [40].
4. *Web-based facility monitoring.* Contractors and facility managers are able to receive alarms; view real-time data manually control and override systems, track equipment performance, and generate reports online.
5. *Use of a centralized data base management system (DBMS).* With the help of a DBMS it is possible to develop coordinated procedures, firm-wide access to information, and ease of distributing and updating information [43].
6. *Integration of project data and knowledge management systems.* Opening windows for contractors and customers into their workflow systems with web interfaces [44].

In a search conducted by Daryl L. Orth [45], it was found out that 20.9% of the asked companies are using project management software, 23.3% plan to use it in a near future, and 53.3% responded that their company does not intend to use web-based projects management software within two years. From the same study it appears that the smaller companies are making the transition to using web-based project management software at higher rate than the bigger ones.

At this time, it is possible to find out many companies that serve as ASP or MSP. Some of them are:

- *eProject.com*. Is a leader providing web-based project planning and team collaboration solutions for knowledge workers. The company enables knowledge workers to leverage the Internet to quickly and easily plan projects, share documents, manage tasks, schedule events, as well as collaborate and work more efficiently with team members.
- *e-Builders Inc.* Is a pioneer in providing construction management applications on the web. It develops business-to-business Internet applications for the commercial construction industry. Its suite of products enable and enhances the exchange of information among construction industry participants and helps projects come in on time and on budget. Additionally, the e-builders open architecture supports the integration of systems with desktops and other legacy applications.
- *Buildnet.* Is focused on residential construction. Its software integrates the back-office system of builders and suppliers, in the same way that modern supermarkets and their suppliers are linked. This permits to increase the efficiency because materials are delivered just in time and automatically, cutting out human error and lowering cost in the ordering process.
- *Bidcom.* Creates a separated website for every building project for clients. Everyone involved from the architect to the carpenters can have access to this site to check blueprints and orders, change specifications and agree delivery dates. Moreover, everything from due dates to material specifications is permanently recorded.

Other companies like *Primavera* and *Meridian* Spar are adapting themselves to the use of Internet. Primavera executive Koppleman says, "Primavera is not taking Primavera's P-3 software and just making it web-bases, but is tying scheduling to e-commerce". From this side, Meridian is focusing on the integration of backend accounting software into its project management software, both as a software product online [42].

Big companies like *Betchel Corp*. are implementing their own web environment for sharing, tracking, and archiving all of a project's documents and managerial decisions [6]. But the company hasn't yet successfully addressed the need to execute decisions through a dispersed work force, nor has it integrated its data with outside companies.

There are two questions to carefully observe when using Internet: the security of information and the time of arrival of information at its destination. Internet fraud is quickly reaching epidemic proportions and threatens to slow the growth of wireless applications. From here the importance of utilizing some secure method for protecting the information. The security of information is solved using the RSA public-private key cryptography. This method produces strong security with 512-bit and 1024-bit keys. However, when dealing with low computational power devices like Smart Cards, PC

Cards, and wireless devices, where memory space is restrictive and faster processing speeds are needed, it becomes mandatory to think in something different. The Elliptic Curve Cryptography (ECC) produces similar results as RSA with 56-, 84-, and 96-bit keys.

Another problem is the timing [46]. As the scope of the e-business expands rapidly, so too does the requirement for global time standards and globally synchronized information systems. Internet guarantees that data will be delivered intact but does not guarantee how long that will take. Frequently it is important in business operations, the time the information arrives. This can be solved first, with a synchronized time baseline across the system and second, with the incorporation of a delay into the server application process to ensure that data from all clients has been received.

What is new related to Internet? First, there is a rapid growth of wireless Internet. ThinkersGroup.com Inc. is marketing a web-to-wireless software that construction company information technology managers may use to translate websites to field project managers who are carrying any handheld wireless device. Autodesk has recently accomplished the use of the GIS Design Server that delivers location-based data via the web. The idea is to give all users, from accountants to field crews, a robust and secure interface with their company's GIS data.

In the near future the mobile Internet will change US industries and business processes, from entertainment to management. A study conducted by Ronald Berger [47], identifies four main trends in the nascent wireless space:

1. The bandwidth game.
2. The standard cell phone will sprout a variety of new functions.
3. The ability to pinpoint a person's geographic position through their mobile device.
4. The consumer orientation of wireless revolution.

3.5. Needs for Re-qualification

The construction industry, like many other industries in the United States, is experiencing rapid change. This change is mainly attributable to the introduction of new technology, principally computer related. The advent of powerful and inexpensive microprocessor based technology has fostered the development of automation in general. Implementation of robotics, complex communications systems, web based project management and information flow, and computer systems in general are all being implemented at a rapid pace.

To deal with the new technological challenges the construction industry needs personnel with skills that were unnecessary just a short time ago. Companies with staff, technicians and administrators unable to assimilate the new technology will be hard pressed to remain competitive and may be facing going out of business.

There are at least two pools for obtaining qualified personnel for the industry:

1) Construction workers re-qualification
2) High school students and graduates

The first alternative is necessary because it is always useful to use personnel with previous construction experience, and also as a way of giving some option to the workers when the new techniques are to be used. Construction companies or Unions shall develop this re-qualification. The second alternative is a very interesting one. High school students and graduates constitute an ideal pool from which to draw qualified laborers to the industry. According to the *Florida Education and Training Placement Information Program*, during the 1997/98 school years 89,850 students graduated from high school in the State. Of these only 45,618 (51%) went on to college. The 49% that did not became members of a frequently insufficiently qualified work force.

Post high school education, however, has been shown to lead to higher paying employment. Figure 3.2 shows the average salary for some occupations in Florida (*Education and Earnings in Specific Florida Occupations 1996*). The first four categories (rows) show the salaries that high school graduates without any other preparation can aspire to earn. The last seven rows show the average salaries earned by those with some type of post-secondary education. The reader is urged to note the difference.

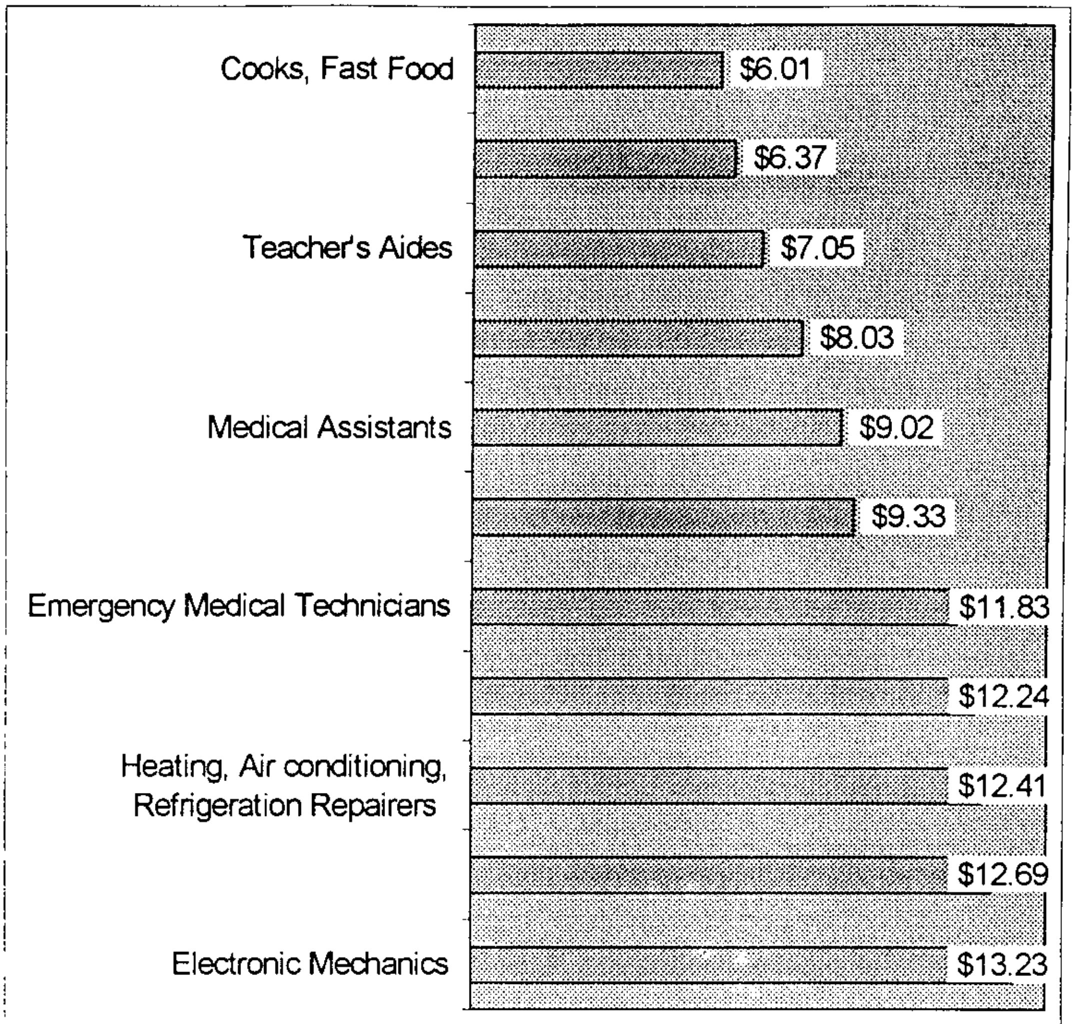

Fig. 3.2. Education and Earnings in Specific Florida Occupations 1996. (hourly rate)

Attracting a part of the high school graduates who do not go to college to jobs in the construction industry would benefit both the youngsters and the industry. If these non-college bound youngsters are enrolled in programs designed to provide them with skills in classical and computer and automation techniques in construction trades, life-long opportunities will become available to them. These young people will be able to get a good-paying job in construction not because they lack other options, but because they are trained for it.

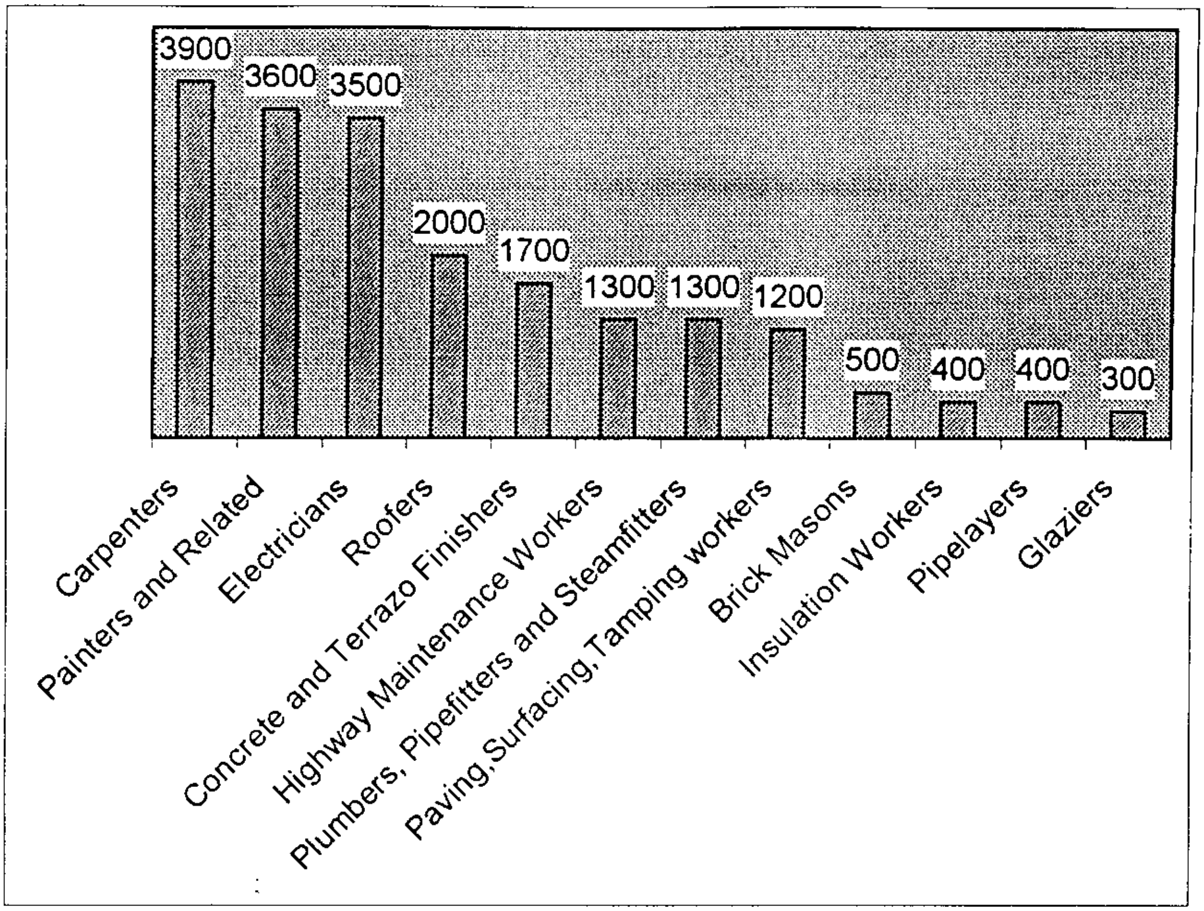

Fig. 3.3. Projected New Jobs for Selected Construction Trades and Related Workers by Occupation (1995-2005).

The statewide increment in construction industry employment from 1996 to 2006 is estimated to be from 325,374 to 346,791 (a 6.58% increase, according to *Industry Employment Estimates, 1998*). Employment is expected to grow slowly for most construction trades and related occupations in the state of Florida during the period 1995-2005 (Construction Trades and Related Occupational Cluster in Florida 1995-2005), either way there will be an increment in selected construction trades, as can be seen in figure 3.3. In reality, the increment in workforce needs will be higher, because it is necessary to add to these figures the vacancies due to personnel that leave the trade or retire.

Preparing these high school students as they progress through their secondary education and after they graduate, in the new techniques using the IT will be very useful for the industry. They have the basic knowledge that will serve for understanding the use of the new technology.

3.6. Conclusions

1. The growing use of computers in the construction industry has not solved the problem of communication between project participants. This has resulted in islands of knowledge, not leading to the integration of the whole process. Computer Integrated Construction (CIC) is a concept, which has yet to be fully realized in the US construction industry.

2. From the analysis of different case studies, it becomes clear that there exists a wide tendency towards the integration of diverse managerial functions: engineering, contract administration, quality control, accounting, commercial transactions, and reporting. Unfortunately, no satisfactory general solution has emerged so far due to the complexity of the interactions and the differences in the methods used by diverse groups on different projects. At this moment, one of the effects of IT has been to fragment the construction industry, because different organizations are at different stages of IT implementation and simply cannot "talk" to each other. The reason is that the software architecture has thus far been designed in an ad hoc fashion primarily to perform individual business functions, such as scheduling, cost estimation, purchasing, inventory management, or financial accounting. In many construction companies such function-oriented applications gave rise to an unmanageable maze of system components, and data could not be easily transmitted to other partners. For solving this situation, interfaces have to be developed to link the various applications. This problem becomes more complicated by the fact that, once instituted, function-oriented structures could not be transformed into process-oriented structures; as a result, companies sacrificed flexibility and the ability to introduce changes. This phenomenon, which is characterized by a high degree of internal integration with very loose or non-existent connections, is called "islands of automation".

3. Currently, the construction industry has found more application off-site than on-site. The off-site automation is basically directed towards the creation and use of intelligent databases and data mining techniques, INTERNET-based project management, 3-D CAD technology and electronic commerce in construction. Among the changes that IT has introduced in the traditional relationships between designers and constructors is the possibility of working like a team, which has the ability to communicate faster, so decisions can be made quickly. It is difficult to estimate what represent for a contractor to have a piece of information today versus tomorrow. Figure 3.1 shows the traditional relationships between owner-designer-contractor. Now that most construction firms are relying on computers and communication technology to perform office functions and project work, these systems are influencing how the different parties in the construction process work together. The connectivity afforded by digital tools makes possible new levels of coordination and management control in single-project associations,

more formal joint ventures, and permanent partnership created by mergers or acquisitions.

4. The basic change with the new technology is that the process can be changed interactively and accordingly to the needs. In other words, the feedback is made more efficient. It is very important for the different parties to sit down at the early stages of the project and work through all the issues, like setting which office standards will apply to the project documents.

5. In the process of automating the information in the construction process, it becomes very important that all participants match the same tools: Microsoft Office, AutoCAD, 3-D studio, Internet compatible E-mail, and file transfer protocol (FTP). The entire team needs to have comprehensive, universal standards that are flexible enough for all team members to participate. Another significant coordination issue is keeping the team's software in synch throughout a multiyear project development cycle.

6. In the near future it is expected that rather than cutting procurement costs by putting pressure on their suppliers, construction companies' IT departments must devote resources to integrate CAD, enterprise resource planning, project scheduling, and other systems to reduce job-cycle.

7. It is possible to find out on the Web many companies that act as "Application Service Providers (ASP)", allowing the customer to access their software over the Internet for a monthly subscription fee at affordable prices. A step further is the use of a "Management Service Provider (MSP)", which manages Information Technology (IT) operations for multiple business, running and monitoring computer networks and software, hosting web sites, as well as providing web access and e-mail. Among the benefits of using ASP and MSP are:

   - Small and medium sized companies can compete with larger corporations without spending a lot of money or recruiting skilled IT personnel.
   - Using project management software on the web people can view the same page on the web with figures that are recalculated as they change, and the two parties can negotiate online].
   - All the software is integrated. So the backend accounting software, for example, is integrated into its project management software, both as a software product and online.
   - The union of scheduling to e-commerce permit, for example, tracking materials from the manufacturer to the job site.

8. In the near future the mobile Internet will change US industries and business processes, from entertainment to management. Four main trends in the nascent wireless space are identified as:

- The bandwidth game.
- The standard cell phone will sprout a variety of new functions.
- The ability to pinpoint a person's geographic position through their mobile device.
- The consumer orientation of wireless revolution.

9. Almost half of the students graduating from high school in the state of Florida don't continue their studies at the college level. These students could be an ideal pool for the construction industry if on a voluntary basis during their studies at high school they would receive some kind of preparation related to the construction industry trades and careers as well as the incoming technology. This will be useful for both; the students who will acquire skills, giving them the opportunity to find well remunerated and respected jobs and the construction industry that will receive well-prepared young people.

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CHAPTER IV

ROBOTICS APPLICATION IN CONSTRUCTION.

4.1 Introduction

Robotics is without any doubt one of the big challenges for the Construction Industry. As stated by Skineiwski [1]. "Automation & robotics has been in all likelihood the most challenging endeavor in the American Construction Engineering Academic Community over the past decade. Several government and private research institutions and laboratories have shared similar enthusiasm for this field. The Industry, including design and construction firms, material suppliers, equipment manufacturers and owners with a few notable exceptions was somewhat slower in relating itself to this new field of research and development activity. However, the process of disseminating the early results from the research and development community to industry practice is now slowly beginning to take place".

There are no universally adopted definitions for the terms 'Construction Automation' and 'Construction Robotics'. For the sake of our discussion, we will assume that 'construction automation' refers to the engineering or performance of any construction process, on-site or off-site, by means of tele-operated, numerically controlled, semiautonomous, or autonomous equipment. 'Construction Robotics' as discussed here, refers to advanced Construction equipment exhibiting any level of capability related to tele-operation, sensory data collection and processing numerically controlled, or autonomous task performance." :

In his last presentation at ISARC 2000, [29] Skibniewski stated, " the number of robots per 10000 manufacturing employees skyrocketed from 1980 to 1996. For example, it increased from 8.3 to 265 in Japan, 2 to 79 in Germany, 3 to 38 in the United states and zero to 98 in Singapore."

The purpose of the study is to review the existing applications of 'construction robotics' and assess their implementation in practice. High expectations of building robotics stemmed from the very serious problems the Industry is facing, which can be presented as [2]:

- Continuously declining productivity
- High accident rate
- Low quality
- Insufficient control of the construction site
- Vanishing of a skilled workforce.

The following paragraphs summarize some of these expectations.
A report describing cases in which robots were already performing economically useful tasks in the field of Japanese Construction Contractors gave rise to a feeling that Construction robotics had become a reality. According to Paulson [3] "perhaps, if no

significant research effort evolves in the United States, American Construction will be able to solve their problems by importing robotics and process control from overseas." Veno et al. [4], after being engaged in the development and on-site application of construction robots for over a decade, came to the conclusion that "the period in which construction robots are adopted as curiosity is almost over in Japan".

Whittaker and Bandari [5] were already looking at the next stage of construction robotics in which a number of robots would work together. This is one of the challenges to face in the application of robots to the construction industry. They reported, "robots were emerging in construction as a way to increase productivity, improve quality, and decrease hazards to human workers". However, these industrial robot forms, though necessary are not sufficient to achieve typical construction goals. Multiple cooperative robot agents must serve the requirement for multiple capabilities at the automated work site.

Skibniewski & Russell [6] say that with less optimistic estimates for construction robotics due to their complex operational environments, it can be anticipated that their application can result in approximately 10-15% increase in overall construction productivity rate." In another paper, Skibniewski [1] reported on early applications in the United States, saying "the process of disseminating the early results from research and development of Construction, Automation and Robotics into industry practice is now slowly taking place". A number of robotics prototypes have been designed and built in the United States and some of them have already found commercial application.

Researchers at the University of Texas at Austin have compiled a database related to classified papers contained in the proceedings of several International Symposia on Automation and Robotics in Construction (ISARC). In the first stage they collected data relating to ISARCS VII-X. Their analysis showed that the number of papers presenting conceptual systems had gone down from about 70% in 1990 to 45 % or so in 1993. At the same time papers dealing with the physical prototype systems were replacing those conceptually oriented, increasing from a little over 25% in 1990 to nearly 50% in 1993. The results of the analysis also indicate a clear trend toward an increasing number of papers on commercial systems, which the researchers saw as solid evidence that construction automation was maturing and becoming a practical and attractive technology.

Regarding construction productivity Demsetz [7] says, "There has been a significant investment in the development of automated and robotic equipment for use in construction. Research laboratories of major Japanese firms have carried much of this work. These firms have a continuing relationship with owners, which allow them to look beyond the bottom line of a particular project. In the United States however, construction firms do almost no research and there is only limited funding available from other sources. Equipment manufacturers and development groups have made some research, but these are primarily geared to the improvement of existing tools and equipment, rather than the development of new equipment. The high cost of machine development and scarcity of research funding has led some researchers to focus first on identifying construction tasks for which automation is most likely to succeed. Five task identification studies have been undertaken to date.

- Warszawski assessed the feasibility of applying robots to ten basic activities required in building construction [28].

- Halpin, Kangari, Abraham, and Cahill[8] addressed the costs and benefits of applying robotic technology to 33 processes selected as good candidates for robotization.

- Alonso Holtorf [9] postulated that a series of economic indices could be augmented by a measure of "physical susceptibility" to determine the building sub-systems best suited for Automation.

- Skibniewski and Russell[10] have outlined a method to assess the appropriateness of a machine for a particular task; they suggest comparing the results of the method with a companion evaluation of human performance.

- The Construction Industry Institute (CII) has recently undertaken the identification and prioritization of activities for construction automation [27]".

As stated by Laura Demsetz [7]:

" 1. The studies completed thus far conclude that construction tasks, which require the treatment of continuous surfaces, are most feasible to carry out with robots, while those requiring the positioning and fastening of discrete objects are the least likely candidates for automation.

2. The C I I study may signal the start of increased U.S. industry involvement in construction automation.

3. The participants have started with a pre-conceived notation of what a robot is and what a robot can do. While the results are valid assessments of the possible uses of robots on construction sites, the more general issue of the potential for automation in construction is not addressed. A second drawback of previous studies is an emphasis on applications in which a machine completely replaces human labor".

From the study it is concluded that in a near future it can be expected that with exception of dangerous tasks, human labor will be required for all the construction processes.

4.2 Implementation Aspects of Building Robotics

Construction is ripe, virtually untouched and inevitable avenue for robotics application. Warszawske and Sangrey [11] have established that robots will be developed and used in a variety of applications and places with local (to the job) conditions being the justification for implementation. The local justification may be a particular hazard or some unique economic factor. The expected sequence of steps in this evolution would be:

- Further automation of existing construction equipment through devices such as Tele-operation, limit switching, numerical control and microprocessors. This process is currently underway.

- Adjustments of building technology to a higher automation level mainly through simplification of finishing tasks and prefabrication of components into assemblies for easier installation.

- Development of robots especially designed for specific groups of construction tasks. The difference between these robots and their manufacturing counterparts will be their load handing capability, reach and mobility. All of these differences will require highest levels of sensing and intelligence.

- Standardization of construction methods, materials, components and methods of communication

- Implementation of methods and mechanisms for the work of several robots in parallel for solving some specific task

In contrast to an evolutionary mode, robots may come to the construction site as part of an entirely new building system. Highly industrialized building systems have been considered for some time. Lower cost and improved building performance are cited as the principal benefits. Two factors now make this revolutionary concept more viable: Robotics plus the use of CAD-CAM and extensions of computer applications into management and quality control. Robotics and CAD-CAM can bring about major changes including; new building materials and components, extensive pre-fabrication, flexible modular construction and vastly improved construction quality.

4.2.1 Robotization of Building Activities

Building construction activities analyzed in the study [12] can be divided into three main groups:

Activities which involve covering or conditioning of continuous surfaces, such as painting, spraying, plastering, trowel ling, screening, spreading of mortar or glue, cleaning, polishing, grinding, sandblasting, etc. These activities can be performed, without any difficulty, at the present stage of technology with the different types of robots such as, a) assembly robot, b) general purpose robot, c) floor flushing robot, d) exterior wall robot.

Activities which involve moving the effector at different location in a pre-determined pattern - linear or point to point, in order to accomplish the required task, e.g., welding, bolting, taping, jointing, grouting, spreading of resident material rolls (for flooring or wall cover), etc. These tasks can also be accomplished without particular difficulty at the present stage of technology if a sufficient precision can be ascertained both in the dimensions of the structural elements to which the tasks are applied and in the access points of the robot from which it commences its task. Since these conditions cannot be assured with the present building conditions, the robot can be usefully employed only if guided by humans, or equipped with sensory devices to monitor its performance. The available sensors are not yet entirely dependable in rugged environment of the building operations. It may be expected, however, that with the present rate of progress, in robot technology, dependable sensory devices could be developed within a short period of time if specifically defined and economically justified by the prospective demand.

Activities which involve handling, positioning and assembling of large and small building components like structural steel, pre-cast elements, timber planks, from work scaffolding, sheathing, siding, tiles, pipes, etc. These activities are most difficult for robotization because they involve very precise storage of often-bulky components, and also due to their need to careful multi-axis manipulation and accurate orientation and positioning. A robotic system necessary to satisfy these requirements must be quite involved and costly.

On the other hand, some activities in this category, in particular the assembling of framing steel and pre-cast concrete elements constitute the very core of building construction operations and simply cannot be omitted from robotics considerations. Warszawski analyzes in his paper [12] that the highest benefits in the building construction field can be obtained from the robotization of these activities.

Construction of many building components requires several activities such as positioning and finishing. Masonry, plasterboard partitions, and siding are examples of such components. Technically robots can construct them. However, the programming and installation for each particular case will be so involved and resource consuming that the feasibility of implementation will be very much in doubt. Therefore, to make the application feasible, it is necessary to delegate as many positioning, correcting, finishing, and joining activities to off-site preparations and utilize on-site ready-made comprehensive assemblies. Such components should be easy to handle, self-supporting and readily connectable to the structure.

The following conclusions can be drawn with respect to robotization of building construction activities [11].

- The number of elements to be positioned should be minimized. This can be achieved by using large pre-fabricated comprehensive assemblies. Small elements - planks, boards, tiles, and bricks - should not be used in robotized activities, except when pre-assembled in the factory into the largest possible (within the constraints of weight, size, and maneuverability) components.

- The components should be designed in such a way that their configuration will eliminate the need for temporary support and bracing during the erection.

- Special fixtures should be built into the components and the receiving structure, which will facilitate their grasping, orientation, positioning and connecting.

- Connections between components should be made as simple as possible.

- Finishes should be selected, whenever possible, from the group most amiable to robotics, namely the group which involves finishing of continuous surfaces.

- Finishes should be made as homogeneous as possible, i.e.. of such technological content that no task will require multiple robot activities for its execution. If a task requires two activities (e.g. spreading and smoothing), they should be technologically designed in such a way that a robot will be able to execute them in immediate succession (or at least from the same station) with two effectors mounted on the same arm.

- There should be an easy access for robot manipulators to all work locations.

4.2.2. The Benefits of Automation

The benefits of Automation no doubt is growing day by day as stated by Demsetz [7], "Automation in manufacturing has provided the following benefits: reduced labor requirements, increased production rate, improved quality, improved safety, reduced scrap, stabilized labor requirements, and improved corporate image. Which of these are likely to be important in construction? Construction is a very labor-intensive industry, particularly in light of current concerns over potential labor shortages; reduced labor requirements could be an important benefit of automation. Time is critical in construction as indicated by the use of bonuses/penalties for early/late completion. Even if labor costs remained constant, increased speed of construction should be beneficial while construction quality is generally considered quite acceptable, if skilled craftsman are available. A shortage of skilled labor would make it difficult to maintain quality. Automation could help maintain construction quality by achieving a constant output over time and by providing built-in inspection. Finally, an improvement in construction safety could be a major benefit of automation in addition to reducing the rate of injury. Improved safety could make construction more appealing to a shrinking labor supply.

Construction is a project based industry subject to large fluctuations in demand; such factors as reduced inventory and stabilization of labor requirements will be of less importance than in manufacturing. For most tasks, reduction in scrap would require change in materials and design, rather than changes in equipment only. While the use of automated equipment could affect corporate image, it is nearly impossile to determine in advance the extent of this benefit. Reduced labor requiremetns, increased speed, improved quality, and increased safety does appear to the most important ways in which automation could improve construction productivity. The potential for benefit through automation will be high when the potential for these improvements is high".

4.2.3. Assessing the Potential for Benefit

Demsetz proposes that [7]: "Two approaches could be followed in order to identify construction tasks to which there is a high potential from automation. The first relies upon personal experience. The participants in construction projects could be asked to list construction tasks when they feel there is a high potential for benefit. Its main advantage is the opportunity to solicit comments and explanations. A drawback, especially for studies of broad scope is the time required obtaining unbiased results".

Loss, J. [16] analyzes the use of statistics in preliminary solution. A review of available data showed that for some of the benefits of automation, relevant statistical information is not readily available. Like automation, preliminary selection must make best use of all available resources incorporating information from survey and interviews where existing statistical data is insufficient.

The following recommendations for benefit indicators are discussed at greater length in [16]:

Reduced labor requirements: High potential tasks are those that account for the largest labor costs. If estimating is computerized, quantity take-off information provides the best source of data. If not, use a survey of estimators wage rates and apprenticeship duration are useful indicators; these are highest for mechanical and electrical trades. Superintendents and foremen can determine if high labor costs are due to long waits for materials, tools and workspace.

Increased speed: High potential tasks are those that occur on/near projects' critical path. If scheduling is computerized, critical path information provides a good source of data. If not, use a survey of schedulers, with supplemental information from project managers and superintendents. Careful checks on the consistency of results with changes in time and location are necessary.

Improved quality: High potential tasks are those that require rework or repair due to poor construction. Due to the lack of published information, interviews with superintendents and foreman should be used in assessing rework. With respect to repair, leaking roofs and problems with concrete work are prevalent. The AEC PIC database [16] could be used for additional repair data.

Improved safety: High potential tasks are those for which accidents exact the highest costs (medical, compensation and emotional). Workers compensation rates provide the most comprehensive source of information. Rates should be multiplied by trades' hours. High injury rate indicates a high potential for benefit for trenching, excavation, roofing, and work done on scaffolding or ladders, and tasks requiring repetitive motion. Surveys or interviews with safety officers, project superintendents, and foremen should be used to obtain further information.

4.3. Social Problems of Implementation

According to Warszwaski [19], the social problems involved with implementation of robotics in industry should be examined within the general social implications of the robotization process in construction:

- The objective need for robotization in building, as perceived by the society, the economy, and policy-making institutions in the various countries.

- The restructuring of a construction labor force due to the automation process.

The statistics in various Countries reveal that productivity is going to be more compelling in construction than in almost any other industrial sector. The data of the U.S. Department of Commerce [21] indicate that the productivity in building construction in the 1970's and early 1980's declined by an average rate of 1.5% per year. Other resources [22,23] indicated an even larger decline in Construction productivity. Similar figures for Japan indicate that, while the average productivity for all industries there increased in the same period by about 10% per year, the productivity in Construction remained constant and even slightly decreased [24]. Similar trends of the productivity decline in building, both in absolute terms and in reference to other industries, have also been observed in Israel [25] and in other Countries. This is attributed by various sources to the aging of Construction workers, decline in traditional working skills, and a tendency of youth to move to more challenging and more convenient tasks. Consequently, many construction tasks especially those associated with tedious, physically demanding, or hazardous work are done by workers unskilled for any other jobs. Sometimes, such workers have to be imported from less developed Countries or regions. The low skills of labor, especially in those undesired tasks, result in an inferior quality of work and a large waste of materials. For all these reasons, it seems that the prospect of automation, at least of some parts of the construction process, is not only highly desirable form a general socio-economic viewpoint but also perceived as such by the public and its various policy making institutions.

The automation of construction work will require some changes in the composition of the labor force involved in them. Workers in charge of robotized construction tasks must be able to teach the robots, start them, monitor their work, and cope with various malfunctions of robots and its materials feeding system. Such workers, or technicians, will need an entirely different educational background and training than workers employed in those tasks in a traditional way. An appropriate training program for the management and the technical personnel will therefore have to be designed and carried out before the actual implementation.

4.4. Current Status of Robotic Application

Warzawski has presented a survey in "Implementation of Robotics in Building: Current Status & Future Prospect" [2]. The general objective of the survey was to determine the scope of applications of robotics in building construction. In more specific terms the objectives of the survey were:

- To review the publications describing the development and implementations of robotic applications in building construction.

- To determine the success of these applications aided by a structured survey. For this purpose exact status of the application was determined for each case.

- To analyze the findings of the survey and draw conclusions regarding the extent of success of building robotics, and the reasons for success/failure......

The survey covered the type of application, the characteristics of robots (their configurations, control, and sensors) the stage of development/employment and the reason for not continuing, if the development/employment was abandoned at some stage. The survey involved all sources of information that were described in the following publications:

- Annual proceedings of ISARC (I-XII)
- Journal of Automation in Construction (Vol. 1-3)
- IAARC's newsletters (1-2)
- Publications of robot developers
- Other trade and academic publications.

The results of the survey showed that the application of robots to building construction is still in a very preliminary stage. Only a very small percentage of the robots (3-4%) could show through their production numbers today an extent of employment (construction sites) a reasonable promise of firm commercial viability.

This very meager success of application can be explained by the following main reasons:

- Insufficient development of construction robot prototypes.
- Insufficient attention in building design to the constraints of robotized construction.
- Insufficient economic justification for robotics in building.
- Difficult managerial environment.

4.5. Future Status of Robotic Application

On the basis of current status of robotic application it can be concluded that there would be a future development for robotic application.

The following general conditions for the use of robots in buildings are extracted from reference [2].

1) The robot has to be construction friendly. All features of operation, movement, material feeding and transfer and their adaptation to the particular conditions of a construction site, must be taken into account in the development.

2) The building design should be "robot friendly". Attention must be paid to the selection of an appropriate building technology to simplify ill-structured (for the robot) building tasks.

3) Better results in robot applications will be obtained in high-precision tasks such as coating build surfaces: painting, fireproofing, and plastering. Also in sophisticated tasks involved in the intelligent application of sensor, and interpretation of the results, such as, non destructive quality control tasks or particularly hazardous or dirty work

4) The managerial involvement is essential in:

- The choice of projects appropriate for robot application.
- Long range planning of the site for robotized construction in terms of material supply of economically feasible building sites.
- Careful planning of the site for robotized construction in terms of material supply, unobstructed robot movements and robot's transfers.
- Enforcement of procedures suitable for robot operation and maintenance.

When all these features are addressed, robots will have available a promising future in construction.

4.6 Design of Construction parameters for Automated Construction

When designing the construction element for automated based construction it must be kept in mind that the construction element must be automation friendly. Architects & civil engineers involved in the design and construction of a building are the intended users. Architects and Engineers always face increasing difficulties while designing buildings and different kind of civil structures. While considering an automated construction process the following questions can be asked:

1. What are the pros and cons of automating construction advance.

2. What are the implementations of automated construction method.

3. What are the boundaries and troubles that must be swallow up by robots and construction equipment.

4. What are the toolbox of principles or rules of thumb that designer could format architectural concept. Provided certain optimization is achieved through Automation.

The first two areas address justification and feasibility and the last two areas describe design.

The use of automated technology must be optimized as stated by A. Scott Howe [26]:

" It is important that design principles based on the technology are considered. Where engineers and construction managers have initiated most of the current research and development from a bottom up approach, it may be advantageous to balance that top – down theoretical approaches initiated by designers, architect and researchers. Researchers can use various approaches to discover rules of –thumb and general knowledge from which designers can draw from. Architects and designers may use automation as a theme or concept whereby the structural, functional and aesthetic components of the building may be derived."

In Fact there is a close relationship between Construction Robot, Design of Civil Structures, Materials Industry, Construction Engineering Site (Field), which must be taken into consideration during automation design.

Another very important aspect is the development of standards for automated construction. Researchers at the national Institute for Standards and Technology are currently involved with three projects related to construction site automation [29]:

- Non–Intrusive Scanning Technologies for Construction status Assessment. This project is intended to initially benefit large earth moving projects and aims at enabling the use scanning technology for real-time, inexpensive assessment and tracking of construction status

- Real-time Construction components Tracking. The objective is to provide infrastructure necessary for the industry to achieve real-time identification and position tracking of manufactured components on a construction site

- Site Measurement System Interoperability and Communication Standards. The objective is to enable the use and integration of multifunctional, heterogeneous sensor arrays by the industry to achieve cycle time reductions in construction.

4.7 Pattern in Robotic Construction study

It has been found that the majority of the automated study and development has been started from the construction /engineering side rather than starting from the design end. In fact Construction Robot compelled the designer to design Robot friendly structures. So there would be a considerable change in the construction materials handling and thereby change in Construction Material Industry.

In fact this area is fragile generally and can be examined as a huge hole in design for automation research. While designing an Automated Construction based structure, an architect must keep in mind that the choice of area within which a robot can contact or carry out work is called a work cell. Work cells differ depending on the design of the robot during building construction .The different responsibilities required to finish the construction ought to be coordinated with work cells of corresponding acceptably designed robots.

In case of material handling it is obvious that construction material would not be as traditional. It is something like heavy and "Construction Robot" friendly. Several authors have discussed the use of material handling in high-rise construction. They describe the use of autonomous forklifts, conveyors, automated lifts, automated storage and retrieval systems warehousing in the construction of high-rise buildings. These systems used together make up a material handling work cells of the various robots and construction machines to the point that proper materials are delivered to each on a timetable. Some other highly developed work in this vicinity has been performed by the internationally organized Intelligent Manufacturing Collaborative (IMS).

Another exceptional example in material handling has been accomplished at Tokyo University. The cellular automated warehouse developed begins to judge the robotic work cell as an element that fills up space. Possibly, any material can be transported or situated in any spot in space, and the system can be rearranged, enlarged, or bonded in the least quantity of time.

4.8. Conclusions

1. The following conclusions can be drawn with respect to robotization of building construction activities [11]:

- The number of elements to be positioned should be minimized.
- The components should be designed in such a way that their configuration will eliminate the need for temporary support and bracing during the erection.
- Special fixtures should be built into the components and the receiving structure, which will facilitate their grasping, orientation, positioning and connecting.
- Connections between components should be made as simple as possible.
- Finishes should be selected, whenever possible, from the group most amiable to robotics, namely the group which involves finishing of continuous surfaces.

- Finishes should be made as homogeneous as possible.

- There should be an easy access for robot manipulators to all work locations.

2. The automation of construction work will require some changes in the composition of the labor force involved in them. Workers in charge of robotized construction tasks must be able to teach the robots, start them, monitor their work, and cope with various malfunctions of robots and its materials feeding system. Such workers, or technicians, will need an entirely different educational background and training than workers employed in those tasks in a traditional way. An appropriate training program for the management and the technical personnel will therefore have to be designed and carried out before the actual implementation.

3. The robotic application has a very meager success in the construction industry. This can be explained by the following main reasons:

    - Insufficient development of construction robot prototypes.
    - Insufficient attention in building design to the constraints of robotized construction.
    - Insufficient economic justification for robotics in building.
    - Difficult managerial environment.

4. From a general point of view, a success in robotic application in construction will be possible if the following conditions are met [2]:

    - The robot has to be construction friendly, and the building design should be "robot friendly".

    - Better results in robots applications will be obtained in high-precision tasks such as coating build surfaces: painting, fireproofing, and plastering. Also in sophisticated tasks involved in the intelligent application of sensors, and interpretation of the results, such as, non destructive quality control tasks or particularly hazardous or dirty work

    - The managerial involvement is essential in:

    - The choice of projects appropriate for robot application.
    - Long range planning of the site for robotized construction in terms of material supply of economically feasible building sites.
    - Careful planning of the site for robotized construction in terms of material supply, unobstructed robot movements and robot's transfers.

- Enforcement of procedures suitable for robot operation and maintenance.

When all these features are addressed, robots will have available a promising future in construction.

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APPENDIX A

BUILDING COMPUTER MODELS

RATAS: (Rakennusten TietokoneAvusteinen Suunnittelu)
In the earlier Phases the RATAS project described some vital elements required for computer integrated construction (CIC). These included the view of one single user interface to general construction information and the basic framework of a building product model for the trade of data concerned with a particular building project.
In the later stages of the RATAS project, sub projects have calculated the product model approach further in feature. A commercial electronic construction information service, TELERATAS was commenced in 1992.
RATAS phase II created a framework for a theoretical building product model using an object-centered approach to information management. The model structure has been applied to different purposes, such as CAD-systems for concrete structures, architecture and different construction field data base applications.

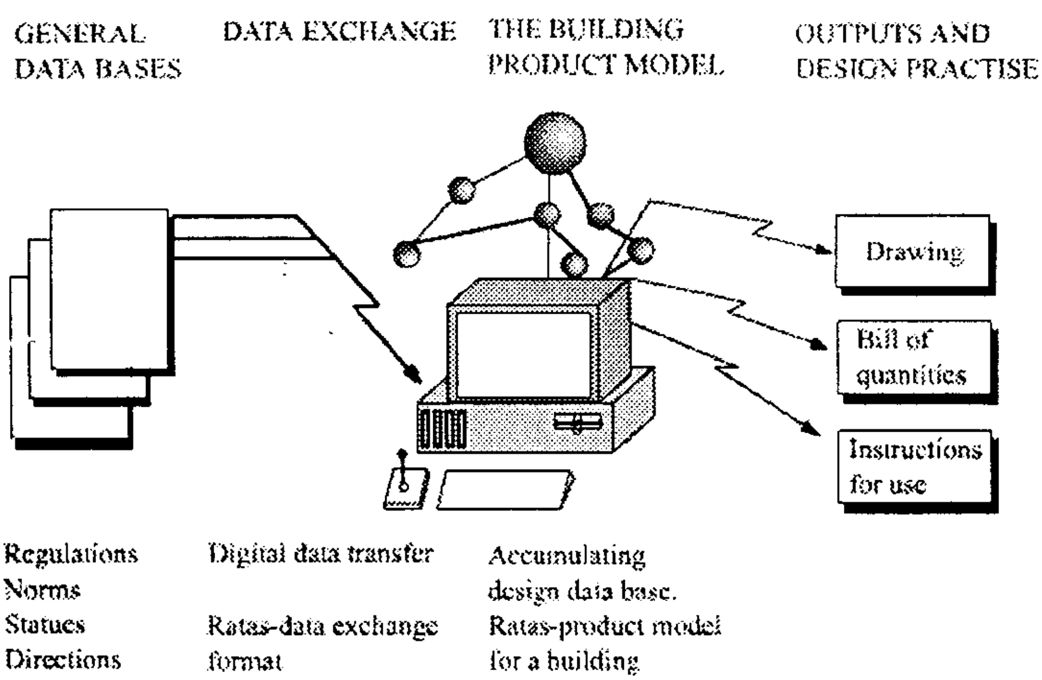

Figure 2.3. RATAS Project, Phase II.

Overall view of the RATAS –project, phase II covered the chain from public general databases, digital data exchange into a building product model database and output documents of the future. (See Figure 2. 3). [1]

The one of the most important authority on the RATAS process has been the research and technology transfer carried out by the Technical Research center of Finland (VTT). During 1989-91 VTT carried out a project which developed further the theory of building product model and tested it by developing prototypes [2]. The approach was established by building four prototypes using progressively more complex basic software[3]

Regardless of some of the setbacks and the troubles encountered, the RATAS project is relatively exceptional with respect to its capacity, period and the participation of the construction industry. Its results should be compared with the results of pioneering activities with similar ambitions in other countries.

CUBE:

The cube system is a prototype that confines and stores information from the building process, and transports it to the exact person at the accurate time. The current contents of the cube Database deals with the construction stage of the building process. Knowledge is stored as couple of questions and replies. Every reply is separated into three division: Straight reply, reply with choices and reply with reference. The cube system was developed to enhance the possibilities to collect and make available knowledge emerging during the construction phase in the life of a building. The demonstrator, who was developed, is used to [4]

- *"Develop and evaluate interface design*
- *Develop adopted knowledge representations and knowledge handling processes.*
- *Make visible technical solutions for communication*
- *In itself serve as a communications tool during the development work*
- *Contribute to the conceptual development within the application area."*

A number of interlinked conceptual models were developed and used in the Cube project. These include [5]:

- "A division of the database into a reference part and a project-specific part.
- The default state of information seeking and the non –modal forms –oriented interface that supports it
- Mark-up systems including a limited vocabulary, a hierarchical classification system and five aspects of the building process.
- Graphical user-interfaces to communicate hierarchical classification systems
- The concept of information refinement comprising a model with a transfer palette to aid the transfer between the answer box and the reference book.
- Relevance ranking using star ratings"

COMBINE

The first phase of the project COMBINE (1990-1992) was to take a first step towards the growth of an IBDS(Integrated Building Design systems) through which the energy, services, functional and other performance characteristics of a planned Building can be analyzed. The extensions of first phase deliverables in the second phase are primarily towards delivering project support to real life enterprise environments. [6]

The COMBINE project is making an effort to develop new building design systems that have credible potential to be absorbed into practice. It is helpful to make a distinction between different levels of enterprise functions in order to grasp the type of barriers that must be removed in order to ensure the most efficient use of new integrated technology.

1. **Operational Level**: At this level Considerable development is being made in terms of standards (e.g. STEP) and tools from software vendors. As far as the building industry is concerned, COMBINE seek to play the role of halfway between emerging PDT & the supply of PDT (product Data Technology)

2. **Tactical Level**: At this level we should be looking at enterprise –oriented support within a project window, which could span the whole of the project or only part of it.

3. **Strategic Level**: We must realize that new information systems change the way that members of an organization think about & organize their work

ATLAS

The ATLAS models describe some of the relevant entities required to share & exchange meaningful data between different Caxx systems used in large-Scale Engineering. According to Frits Tolman and Patrice Poyet [7] "*For the model developers the two most important tactical objectives are 1) To develop , implement, demonstrate and to evaluate open solutions for the sharing and exchanging of information between different sectors of the LSE industry, different disciplines, different life cycles stages , different LSE application tools and different companies 2) To contribute to the standardization process by submitting the reference models and application interface specifications to the appropriate standardization bodies.*"

Objective 1 (as described above) first required the extension of product models with typical project data. Second fulfilling the requirement that communication should be tailored to the specific needs of the parties involved in a project led to the development of the three-layered model architecture. Third, the required support for project life cycle integration by developing view type models that describe the relevant data of each project life cycle stage separately and by developing a flexible Building Kernel Model that can be used for each life cycle stage. Objective 2 made us turn towards ISO-STEP. All ATLAS deliverables will be obtainable in STEP format (EXPRESS) and will be made input in the STEP standardization process. [8]

CAFÉ (CONSTRUCTION ALTERNATIVE FUTURES EXPLORER)

The Project Started with the objective of producing a ' generic scenario' formed by welcoming construction managers to generate a series of plots about how they saw the prospect of the construction industry rising [1]. Having produced these ' scenarios', they could be evaluated and from them combining familiar elements could be obtained a 'generic scenario'. The 'generic scenario' would then be used to recognize ' Key leading markers of the upcoming atmosphere'.

The value of CAFÉ is that it provides a logical and consistent approach to the extraction, Structuring, analysis and presentation of data, which is relevant to informing strategic thinking and to thinking strategically about alternative futures.

The benefits of CAFÉ are according to Brightman, Heijden, and Langford [9] "1) *Display, manipulation and integration of a vast quantity of 'soft' information from diverse sources 2) Analysis and Structuring of soft information, building ' causal narratives' about the future in a logical manner 3) Exploration and widening of managers' perceptions of their business environment 4) Focusing of attention on, and the stimulation of, thinking about he future in a new and innovative way.*"

KERNEL

The function of the kernel model is to provide a basis for communication between the different disciplines. As a result of this, the kernel includes exactly all information that is communicated between disciplines. In the case study (case study can be seen by reference [10]), the contents of the kernel remain small and manageable. When other views are added, such as the architect's view and the HVAC engineer's view, the kernel will become a lot more complex. This is due to the fact that kernel includes all information that is communicated between the different disciplines.

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