CAD-So What?

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Abstract

Computers were applied in construction towards the end of the 50s. In the meantime CA-X technologies rapidly evolved in areas such as integration of application software, 3D modelling and simulation, multimedia systems, artificial intelligence, CADCAM, robotics, and computer-based integration of design, construction and facility management. The structural changes under way in the construction industry ask for a transition from mere CAD, where ,,D" stands for design and drafting, towards CAC, where the second ,,C" represents construction , thus further processing the previously generated CAD data

Introduction

Computer applications began evolving in larger construction companies in the late 1950s primarily in the USA. Breakthrough computer-based project management techniques, such as the critical path method (CPM) for scheduling, were developed at about the same time, and also moved quickly into the construction industry

The 60s and 70s saw steady progress mostly in the USA, particularly in home-office applications such as accounting and finance, though the impact did not match the revolutions that took place in other industries. Project-oriented applications such as CPM scheduling, estimating, simulation and plotting evolved, but till the 80s their overall success remained far below early expectations. Initial problems related to costs of and access to computer hardware, complex software, user-unfriendly humanmachine interfaces and unpractical interpretations of the results. But the most important omittance was the negligence of qualifying on-site crews for this computer technology.

In the 1980s microcomputers became widespread and rapidly decreased in cost; finally easy-to-use application-development software, such as spreadsheets and databases, was introduced. We now more often see CAD and microcomputers at work on construction sites, and the people using them effectively know how to apply software tools for estimating, scheduling and cost control. Due to the imminent structural changes in the construction industry the further processing of CAD data will be a strategic key for survival of many small offices and SME's during increasingly chaotic market conditions to come.

1. Present CAX Trends

While it is more difficult to predict the dissemination considering human and organizational barriers the integration of existing applications, 3D electronic modelling and simulation, and multimedia-based systems have overcome the technical obstacles for widespread implementation.

2. Integrated Applications

In the 1970s and 1980s many problems resulted from the development of mainframe and minicomputer databases which frequently tried in vain to integrate construction applications. CAX-construction applications have been implemented in relatively selfcontained packages, and there are some major compatibility barriers to exchanging even file-level data among many of them. Finally now developers of system and application-development software are making it easier for designers of application software to interface to other applications. Furthermore commercial developers of related packages, such as estimating, scheduling, cost control and CAD, have been working together to provide better interfaces for moving data between their packages. It became possible to take a set of standard package applications and link them together in a manner that resembled an integrated construction information system.

The planning, scheduling and performance-measurement functions can be handled by network-based project management packages. The interface from CAD to estimating facilitates the calculation of lengths, areas and volumes (e.g., earthwork and concrete), and transfers a bill of materials for items that can be directly priced (e.g., plumbing and light fixtures) and entered into the procurement system. Dynamic CAD, if it is used as an ,,as-built" model during construction, can potentially be used by owners and operators for their facility management. As far as estimates are concerned we need to move from mere statistical estimates, which can only react to the estimate overrun, towards an active realtime estimate control. This type of estimate has several useful outputs to other systems. Its crew production estimates send resource requirements and time durations to the scheduling system; its categorized estimate of costs forms the basis of a budget for the job-cost system; and its quantities and materials feed into the procurement system. Procurement information flows into both the job-cost system and into the accounts-payable component of the accounting system; both of these are well established links that are available in most high-quality accounting packages. Job cost provides input data to the accounting system, particularly for the payroll and accounts-receivable billing modules.

But these applications all fell short, since the CAD data could not efficiently be used for real time control of the actual construction process. Basically what has happened to CAD was that it has been used in the conventional way of thinking and designing with

„paper and pencil" and existing design habits prevailed without restructuring the design and construction process according to the potential of CAX technologies. What is really needed is the redesign of existing organizational, technical and qualifying habits in such a way that CAX technologies can increase the efficiency of the integrated construction process.

3. CAD-YR (Virtual Reality)

Computer-aided design software is finding its way onto construction project sites, but already designers in the AEC offices are making use of three-dimensional "walkthrough" simulations. These graphical simulations provide realistic views into designed space long before it is constructed. Problems ranging from component interferences to subtle problems with HVAC can be caught well before their realworld costs and resources are determined.

By adding a time base to the simulation, architects and managers can see how the components are installed over time, experiment with different sequences, and play the result like a video animation to clearly communicate the plan to field supervisors, crew members and even Do-it yourself builders. Some systems also add scaled 3D images of major pieces of construction equipment, such as cranes and trucks, robots, ABCS, in order to help users explore with the computer actual materials-handling methods. Byproducts of these simulations can be short-interval schedules, resource requirements, and materials logistics details, which can be sent to scheduling and database software.

As workstations become faster and "virtual reality" devices become practical, more complex, continuous and realistic images will look and behave almost like the construction process itself. It will have important applications in operations planning, worker training, and facility management for future construction projects. Even though YR looks promising, it will not be effective as long as it is just used as a nice animation toy. What we need here is the further processing of YR data for programming construction machinery and controlling the actual construction process.

4. CAD-MM (Multimedia)

Multimedia computing systems have been moving rapidly into training functions in many industries. Their economics and teaching effectiveness are complementory and maybe even superior to traditional training methods, even though they are still in a fairly early stage of development. As the technology becomes an increasingly standard part of future workstations, this training function can be extended to teach people how to use other types of computer applications in remote, inaccessible, rural or third world regions.

In prototypic industries like construction, where the logistics have to cover considerable dimensions asking for unprecedented management decisions, it is difficult to make the methods and techniques developed on one project available to people who could use them on other projects; the industry is therefore criticized for its prototyping attitude whenever a contract has been aquired. Just imagine what would happen, if the car industry would sell prototypic cars through their dealers! Multimedia technology could provide a means to record innovative and productive methods to build up a corporate memory that can be accessed by the planners and managers of future projects.

Another strategic benefit of multimedia technology could be the temporary establishment of virtual offices or companies in order to aquire design and build contracts. This would be a strategic tool for SME's and small architectural and engineering offices to compete in future construction markets even on a global scale by the internet.

5. CAD-Al (Artificial Intelligence)

Examples to be considered here include artificial intelligence, CADCAM, robotics, and fully integrated construction project planning, design, management and production control systems.

Already there have been many efforts to apply the evolving computer science software technologies loosely called "artificial intelligence" (A!) to construction. So far, most construction investigators have focused on techniques called "expert systems" and "knowledge-based systems," although some have recently been moving into a new area called "neural networks."

The main reason for trying to apply such methods to construction is to deal with the qualitative and ad-hoc based types of problems that are so prevalent in those parts of the industry where the construction is mostly executed on-site. The most valuable career asset for a construction professional is not mathematical or scientific skill of the type taught in engineering schools, but rather it is a methodology to use the not yet existing human experience to solve new problems. Another objective of construction is to capture the knowledge of experienced architects and engineers in computer programs so that other construction engineers and managers can access it and apply it, perhaps even after the experts who provided the knowledge are no longer available due to personnel fluctuations. Such programs also provide a means to integrate and validate the knowledge and experience of many experts, and thus provide a means for accumulating and improving a body of knowledge over time. A good example of this sort of knowledge are the 800 precut systems currently in action in Japan, where the craftmanship of the famous ,,daikusan" or carpenter, who could carf all the traditional japanese joinery, has been programmed and generated CADCAM production of traditional joinery at affordable cost. Furthermore this type of knowledge could be very helpful considering the long product life cycle of the built environment and retrieving it for future recycling.

Implicit in this type of computer application is the need to deal with uncertainty in the information needed to design, build and operate a building. For example, design starts with only general conceptual knowledge of what a project will look like when it is completed. Yet as early design decisions evolve into commitments for configurations, materials and systems, they can adversely affect constructions costs and schedules, and compromise the efficiency and effectiveness of facility operation during the whole life cycle of the built environment.

AI techniques can capture knowledge of construction methods and management making this available at the design stage during which about 70% of the construction costs are determined. For example, if a designer has a choice of configurations for a wooden structure, an expert system could provide advice as to which would be most economical to build.

A promising area for future applications of A! technology is in planning, monitoring and controlling the construction process and costs in real time. Up to date we controll construction costs statistically instead of adjusting the process in real time. Already there have been some good attempts to build construction planners of various types, and other applications have been made to analyzing construction contracts, preparing construction cost estimates, and select construction methods. Other important applications for intelligent agents will be in helping people to coordinate the vast amount of documentation that is generated in a large construction project, and to assist in negotiating the long and complex permitting procedures that are now required for most projects. Probably the most interesting applications will occur when A! techniques supplement or replace the procedural programming that is now used for one of a kind prefabrication, automated machinery and construction robots.

6. CADCAM (manufacturing)

Development in the field of construction being predominantly characterized by increasing shortage of skilled labour, this shortage will have to be compensated for by an increase in the level of prefabrication to be achieved in the manufacture of pre-cast concrete, wooden, steel frame and brick wall building elements. As an example I describe here the increasing market demand for pre-cast concrete ceiling elements and pre-cast concrete wall elements to pre-cast concrete columns and beams, but due to shortage of paper length I can not explain the same for the other materials, but I will show advanced precut systems for wooden elements , steel element factories and automated brick wall facilities using my slides

On the basis of the development of the European market for that product, the intention to invest in that product can be regarded as farsighted and promising of future success. The application is available for the most advanced CAD and CAM technologies currently available to the manufacture of double wall elements, massive walls, ceiling and roof elements, column and beam elements. As there has never been any plant automated to this degree, development tasks will continue to account for a large percentage of the work to be done.

In traditional manufacturing in high wage countries the share of labour cost increases faster due to low mechanization rate. Applying mechanized manufacturing methods allows labour cost share reduction up to 30% by increasing mechanization rate. According to the mechanization ratio a minimum lot size of about 30 elements is required. Most gains can be achieved by automated manufacturing using robots, CNC machines and FMS in order to further reduce the significance of labour costs. Traditionally automated factories required a minimum lot size of 1000 or even 10.000 pieces to guaranty ROI. Through the use of FMS (Flexible manufacturing systems, robots, off line programming methods, hybrid control systems etc.) it became possible to run a one of a kind production efficiently. Most present day CADCAM factories reach their ROI point after 3-5 years. They can run 1-3 shifts, producing 1500 to 2000 m2 (16,145.88 ft' to 21,527.84 ft) of floor-wall panels per shift.

Another substantial advantage in favour of the pre-cast con-crete elements consists in the job efficiency of the workforce. As the building site personnel is to a far lesser extent concerned with somewhat more complicated tasks, such as, for example, moulding, insertion of reinforcement steel, etc. than is normally the case with regular construction workers, job efficiency at the plant level reaches an optimum that cannot possibly be arrived at on a building site. Costs of transportation are approximately the same both for the prefabricated elements and for corresponding quantities of sitemixed concrete.

An increasingly competitive construction market asks for new flexible production as well. Due to the notion of robotic handling devices any shutters can be freely positioned. Recent trends in flexible manufacturing technologies offer solutions for PC production placed on a platform using magnetos. This development allows to cast free shaped and designed panels in concrete and produce one of a kind elements very efficiently as required. What we have to do next with the CAD data is to use them for rapid precast concrete production by robotics as strategic advantage for improving quality and staying competitive during chaotic market conditions. Similar technologies are available for wooden structures using precut-CADCAM-production systems or for autoclaved lightweight concrete which can becarved by three dimensional milling center.

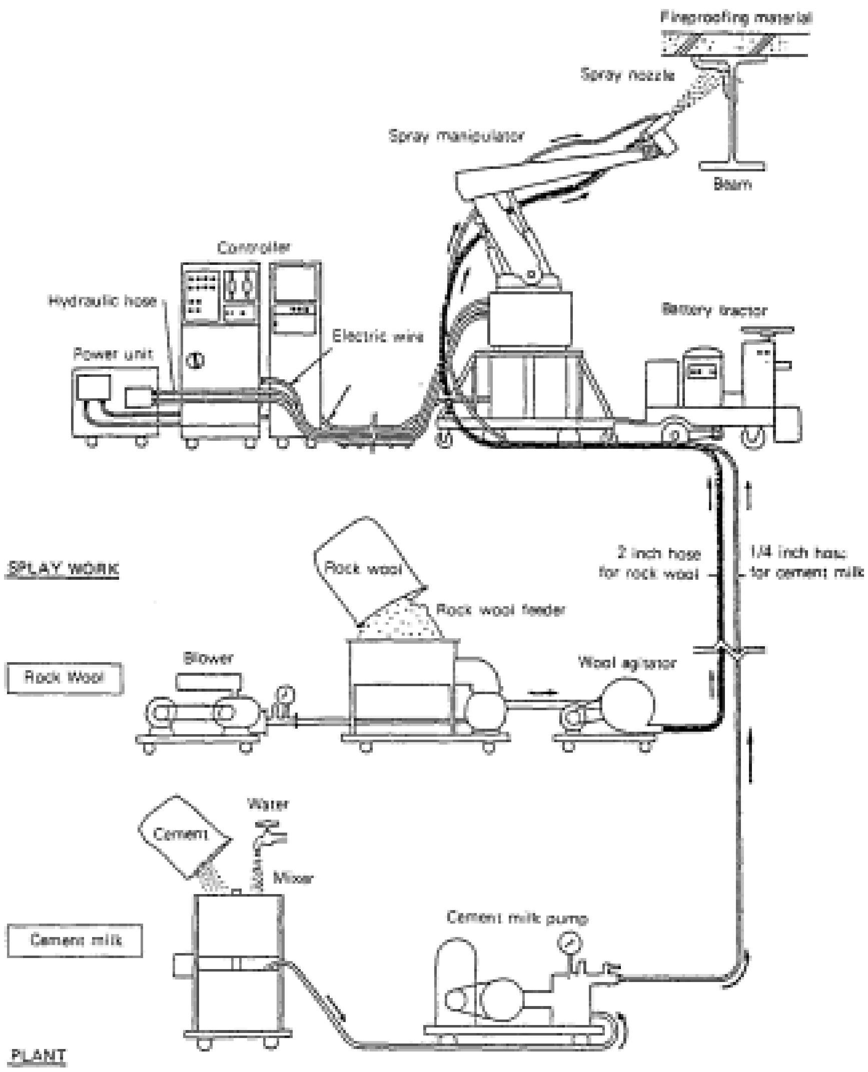
7. CAD-C R (Robotics).

Considerable benefits of CAD will be realized, as soon as we link it up to any kind of machine or robot in order to implement computer integrated construction. Here I describe the progress and obstacles faced by the first generation of construction automation and robotics which have been developed and tested during the 80's mostly in Japan and the greatly increased potential that will be evident in automated building systems, which are tested in the 90's and will be furthermore implemented in the first half of the 21" century.

The challenges of developing robots for construction jobsite are much greater than those of most factories. First the products of construction are much more complex and ill structured. Second, in contrast to the repetitive products that flow down production lines, the design of the construction product and the process to build it are individually adapted in each case. While the manufacturing process is highly repetitive once production starts, that in construction is always changing. The physical environment of construction is often much more hostile to machines as well as people, so machine design must be stirdy and robust accounting for extremes of weather, dust and unexpected forces.

Given the difficult and complex environment of construction, it is remarkable that robots and automated machines are already performing routine tasks on some jobsites. The first construction robots have either been derived by adding sensors and computer-based controls to existing construction equipment (e.g., to control the cutting edges or screeds on various types of earthmoving and paving equipment, robotic tower crane etc.), by adapting the comparatively rigid factory-type robots to construction (e.g., for spraying fireproofing material or painting), or by developing hybrids of the two (e.g., robot arms mounted on tunnel machines). While the sophistication of their mechanisms and sensors has often been quite high, these robots have had only the most basic forms of on board "intelligence."

Most of the construction robots developed to date are stand-alone devices designed to perform narrowly defined tasks without the need to communicate or cooperate with other machines. However, coordinated teams of robots quite commonly perform sequential operations on factory assembly lines, and there are some formal communication mechanisms linking them together and similar technology also moves



Rock wool spray system with SSR-1

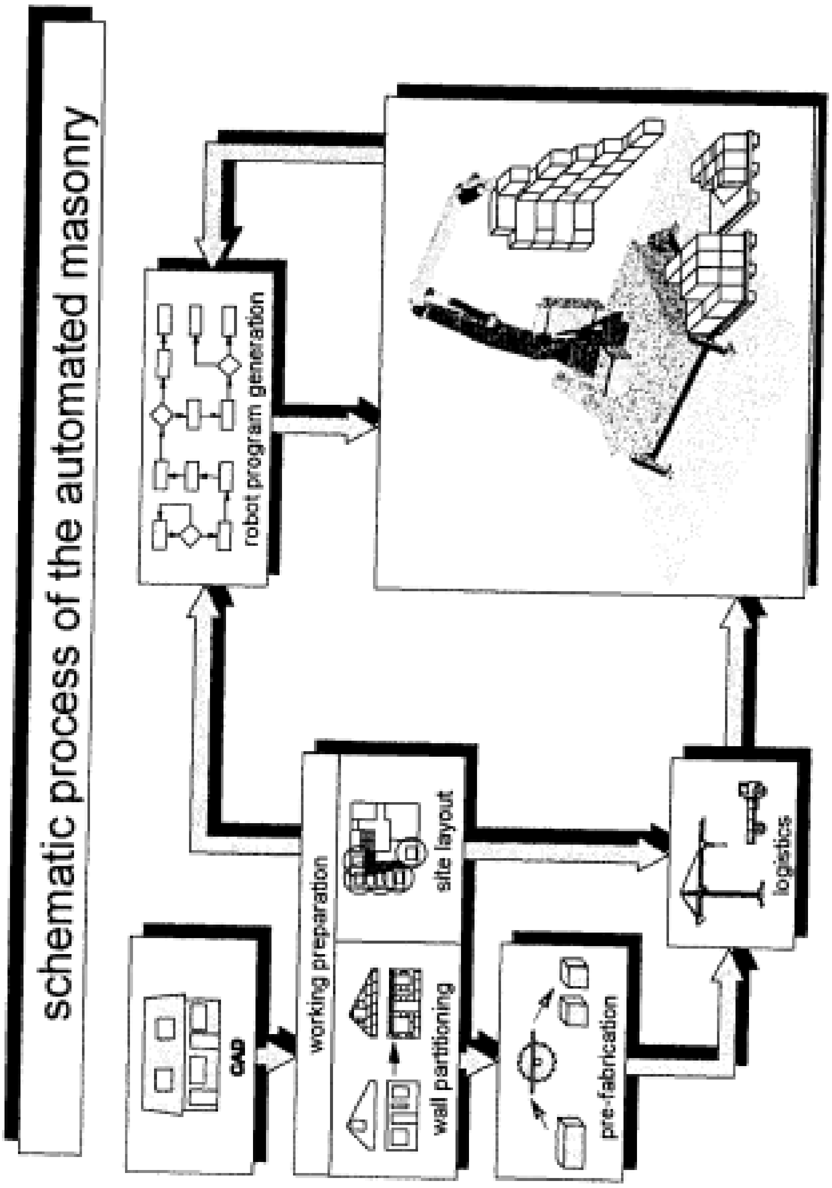
to construction in the dozen or more automated building construction systems or the EU project ,,ROCCO" which stands for robotic assembly system for computer integrated construction and has been scientifically guided by the author:

7.1. ROCCO: Robotic Assembly System for Computer Integrated Construction

Here I describe only the IT part of the ROCCO project: The system deals mainly with the construction oriented modification of existing technologies and with closing the gaps between them through intelligent interfaces and IT-based tools, in order to provide the necessary flexibility for one of a kind building production, robust design and user friendly programming. To achieve the requirements, the above mentioned basic strategies for automated construction are applied: the information integration
the transfer to the pre-fabrication (only where applicable) and the redesign of the used construction materials. The main emphasis lies on the creation of automated system, which enables the complete and continuous automation and the integration of computer based construction systems, without restricting the freedom of the design of the architects. With that system one can build in a shorter time with fewer personnel more and better buildings.

Within the ROCCO project a mobile robot system will be developed for the assembly of masonry on-site. Therefore a suitable robot under development as well as the integration in a computer based system for the working preparation and programming. The robot system with a reach of 5.50 m and a load capacity of 350 kg consist of a vehicle , the actual robot or manipulator and a gripping and assembly tool. In the framework of the working preparation, the necessary data for the pre-fabrication of the costumized blocks and for the robot programming are generated.

Based on a CAD representation of the building, first the walls are divided into the single blocks automatically by a software tool. The next step contains the planning of the construction site layout, i.e. calculation of the optimal working points of the mobile robot systems, the space for the pallets, the configuration of the blocks on the pallets and the sequences of the block's assembly. With the then available information the customized blocks for realizing individual wall dimensions can be produced, cutted and palletized on stationary plants. The last step of the working preparation is the generation of the robot programs.


schematic process of the automated masonry
CAD
working preparation
wall partitioning
site layout
pre-fabrication
logistics
robot program generation

7.1.1. ROCCO 's integrated information management

The chosen approach bases on the idea of Computer Integrated Manufacturing (CIM), which is already successfully implemented in other industries and which shows there its efficiency. The idea is a continuous information flow from the architectural design to the automated execution of construction process on-site and in consideration of the construction elements. This procedure, called Computer Integrated Construction (CC), makes it possible to automatically process all once collected data without loosing the data consistency. This enables all participants to stay as flexible as necessary during short-term changes with as low error rates as possible.

The different development stages of the information flow between the parties participating in a construction process will be shown exemplary by means of the chosen application: masonry. The concept of CIC leads into the components and tools described as follows.

7.1.2. ROCCO 's information flow

Conventional information flow. Until the introduction of CAD-systems for designing buildings, all information necessary for masonry construction was included in the manually drawn architectural design plans. These plans where send to the executing construction company, who ordered with them the necessary building materials as non-costumized prefabricated standard products, adapted it according the plan sin a handicraft manner on construction site and assembled the walls manually based on the information of the architectural plans. This procedure implied in each of its steps big sources for errors, which resulted in delays, subsequent work and bad quality of the construction.

Advanced flow information. In the last years, computer aided design gains more and more importance. The use of CAD in architectural offices is increasing rapidly and with this the availability of electronically processed data, which causes more exact and consistent plans. An additional trend can be observed in the building material industry. They are increasingly able to produce custumized non-standard blocks through computer aided working preparation and production, which can easily assembled on the site according to automatically generated assembly plans without the necessity of a manual re-shaping. Hereby the information flow is reversed by the building material industry. They get the information in pre-fabrication directly from the architect and pass the assembly plans and parts lists to the construction companies.

7.1.3. The ROCCO GIG information flow

To integrate the complete construction process in an IT-framework, as many as possible process steps should be based on electronical data processing. For the masonry we describe following a complete integrated information chain from the architect's design to the robotized execution of the tasks on-site, where all tasks are based on electronical data processing. This concept is IT backbone of the ROCCO project and represents the state of the art in European computer integrated construction systems.

The plans in the architectural offices are created with CAD-systems. On these base the production of standard and non-standard blocks in the pre-fabrication with the computer based production scheduling and numerically controlled production. This enables again the use of programmable assembly tools and systems on the construction site. The corresponding information flow is shown on the picture below.

To use the architectural design data for production planning and programming in the prefabrication and on the construction site, it is necessary to process and to extend the data. The necessary software systems will be presented in the next chapter. The development of the software tools is realized within an interdisciplinary group on the base of already available knowledge.

7.1.4. ROCCO 's systems components

A basic difference between conventional robot applications, e.g. in mechanical engineering, and the robotized masonry is the number of repetitive robot motions. In conventional applications the same set of motions is repeated thousands of times, whereas every house has a unique design and every block has to be placed with an individually set of motions. However, at the same time we can reduce the structure of the motion process to some basic pattern like gripping, positioning, placing. This helps to reduce the complexity of the task.

A crucial importance has the programming of the robot. Normal robots can be teached or programmed with off-line programming-systems, where much more time is necessary to program the sequences than to execute it (but for the efforts are distributed to the number of cycles). This is not possible with a one of a kind production. Here an automatic program generation based on the available geometry data is compelling.

For this the start point on the pallet and the end point in the wall of each block must be known. Additional the position of the robot in relation to the floor must be known. This leads to another difference between industrial robots and on-site robots. The onsite robots are exposed to permanently changing environmental conditions. It is necessary to re-calibrate the robot at each working point. In addition unknown obstacles and events may occur, which make it necessary to adapt the robot easily to the environmental conditions.

During the whole working sequence, it is necessary, that the operator knows exactly, what statement is executed by the robot and how this can be manually modified, if environmental changes or material breaking occurs. The main difficulty lies in the reentrance of the generated program after a manual modification, since the decision is necessary, at what point and with what parameters the program will re-start after unpredictable manual operations. To solve the problem, advance programming methods must be applied, which allow the simple and fast modification of the generated program.

We choose a distributed database approach to be able to run the different parts of the software system on different platforms (adapted to the respective requirements) and at different places, i.e. at the working preparation office, at the pre-fabrication plant and directly at the robot's working points on-site.

7.1.5. ROCCO 's off-line components

The used computer platform for the working preparation at the building material producer is a high level PC running the OS/2 operation system with the integrated OS/2 database manager. The relational database serves as the central storage and information distributor for following applications:

- Different CAD-format converters, which convert the architectural design information into a process-able format

- The graphical user interface, which enables the user to collect data from manually designed houses and to show the result s of the following information processing systems.

- The wall partitioning software, which divides the architectural walls into the necessary blocks under the consideration of windows, doors, lintels, etc. The outputs are the dimensions and positions of each block in the respective walls. During the segmentation procedure, optimization criteria have to be considered under hard boundary conditions. The number of non-standard blocks should be minimized to keep the costs low and the dimensions should be well balanced to keep the waste during cutting low. Simultaneously official and technical prescriptions should be kept concerning the bearing capacities, the joints' positions, the walls' connection, etc.

- The sequence and task planning software, which is responsible for different calculation and optimization procedures. In the first step, the software has to determine the possible assembly sequences of the blocks, that is to generate an assembly precedence graph. In the second step, the optimal sequence has to be determined concerning the optimization criterion of minimizing the number of vehicle movements respectively of maximizing the number of blocks built from one working position. This is mainly dependent on the reach of the manipulator. During the calculation of the optimal sequence, one can simultaneously determine the number and positions of the necessary working points. In the next step, this information is used to generate a collision -free path of the vehicle from the first working point to the last one along the sequence of working points.

- The palletizing software, which determines the position of the blocks on the pallets and the sequence and positions of the pallets on the construction site. Necessary information are the assemble sequences related to the perspective working points, the dimensions of the blocks and pallets, the position and dimension of the free storage space around the robot and the specific properties of the gripper, i.e. the gripping direction and for that the free reachable block surfaces. The main intention of the tool is to minimize the number of pallets under the condition of guaranteeing the necessary free reachable surfaces of the blocks for gripping. To achieve this goal advanced operation research algorithms as heuristics and genetic algorithms are applied.

After processing the incoming CAD-data with the above described tools, all necessary geometrical information as the positions and the dimensions of the blocks on the pallets and in the wall as well as the positions of the pallets and the robot system are available. Together with the assembly sequence, all data is onhand to be able to generate the control programs for the pre-fabrication production and cutting machines as well as for the on-site assembly robot system.

7.1.6. CAD controlled pre-fabrication of building components

The operation in the pre-fabrication plant can be divided into two basic procedures. First the production of standard blocks in different formats. The production is not specific for a certain order. No custumization is necessary. Therefore the only necessary information for the production scheduling is the number of blocks and their main format. So non specific software tool is necessary to process the data before using it for the production of standard blocks.

Another situation is in the production of the non-standard blocks as the second main procedure in the pre-fabrication. To get an efficient production of these blocks, it is necessary to have a continuos information flow from the above mentioned off-line tools to the production machine controls. If one wants to assemble the tools automatically, not only the dimensions should be known for correct cutting but also the positions on the pallets for correct palletizing. To get an efficient production procedure, both, the cutting and the palletizing, should be automated. For both numerical controls with well-defined interfaces are necessary. In both cases, the geometrical information must be converted into motion information of the respective axises. Additional the sequence of cutting must be optimized to minimize the cuts and waste under the boundary conditions of the features of the used cutting equipment and of the succeeding palletizing station. So, three different software tools are necessary described below:

- The cutting sequence optimization, which minimizes the waste number of cuts considering different boundary conditions: The features of the used cutting equipment as the number of saw-blades or the thickness of the saw-blades, the features of the palletizing equipment as the ability to palletize randomly or the maximum number of the simultaneously available pallets. The software uses similar algorithms as the palletizing software in the one-line field.

- The cutting program generation, which processes the geometrical information of the blocks into the motion information of the respective NC-controlled cutting axises.

- The palletizing program generation, which generates the motion programs for the palletizing devices. The generator has to consider not only the necessary final positions on the pallet. Depending on the design of the gripper, it is also necessary to consider the already palletized blocks in order to determinate the approach direction to avoid collisions.

The fully automated and computer-integrated pre-fabrication of the blocks represent an important prerequisite for a smooth assembly process on the construction-site.

7.1.7. Construction Site IT Components

After a conversion, the geometrical and process data are available in a format, which is suited to serve as the base for the robot program generation and the user interface for the robot control. The figure below shows the complete structure of the software components. Here we chose an object oriented approach to implement a hierarchical implicit programming system to meet the following requirements with simultaneous ease of use, extendibility and programming power.:

Requirements: Integration of simulation packages, input and administration of world, sequence and program data, integration of path planning algorithms, providing of programming features, real time capability, interfaces to robot controls and measurement systems. The system consists of an implicit layer, were the working sequence is described in an abstract, robot independent manner on three hierarchical levels: Mission, task, action. Each of the levels offers different commands to be used for the description of robot operation. With the representation of the different operations as icons in a precedence graph, it is possible to provide an easy to use programming feature without the necessity of the knowledge of a programming language. Also the automatic program generation is possible, since at the point only the assembly sequence information is necessary. The picture below shows the operation hierarchy.

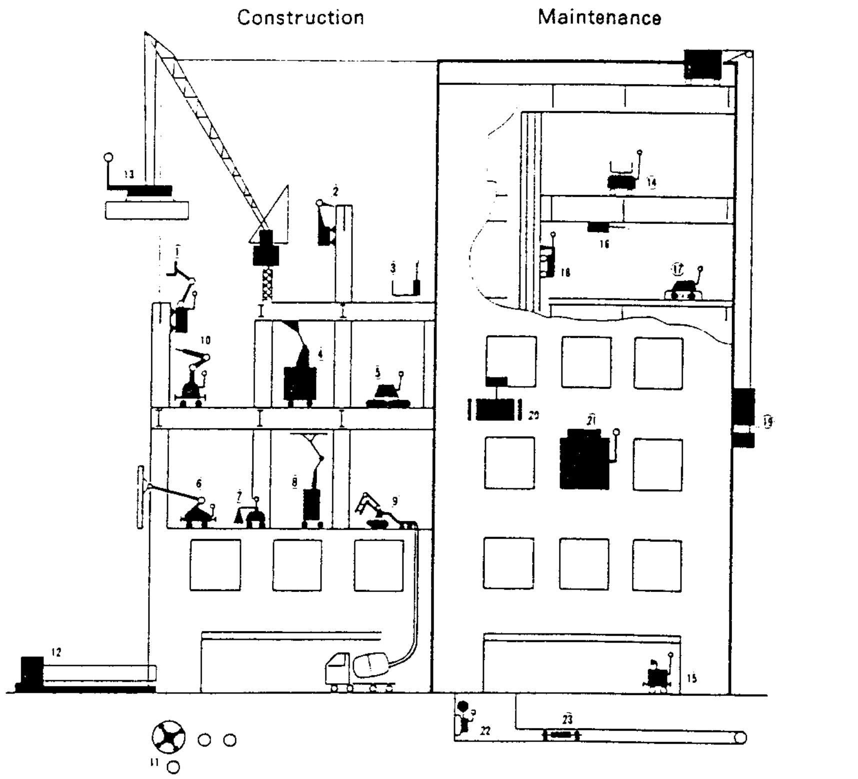
The second layer converts the implicit instructions into explicit elementary operations (EEOs), still robot language independent, but now provided with the explicit geometrical parameters for robotic motions. It is possible to integrate in this layer the automatic off-line planning, where the respective geometrical information can be used to parametrize each elementary move of the robot under the boundary conditions of a collision free path and consideration of the gripper features.

Through a succeeding interpreter layer, where the universal motion commands are transferred to the robot control dependent commands, it is possible to integrate different on-line control, sensor and simulation systems. Through the real-time process monitoring, it is possible to include sensor information in order to follow the execution and to update the world database even after switching from automatic to manual mode and vice-versa. One can integrate alternative manual operations either in the feed forward and nominal feedback line, if the assembly of difficult parts is necessary, or in the non-nominal feedback line, if the assembly of difficult parts is necessary, or in the non-nominal feedback line, if the sensor detect an irregularity or problem during execution. This strategy enables a flexible reaction to all unforeseeable situations on the construction site, which can be handled either through manual reprogramming of the automatic operation.

By describing this ROCCO project I wanted to show how we have to make efficient use of CAD data, because then we can increase the productivity of the whole design and build process.

8. CAD-ABCS: Automated Building Construction Systems

A major step toward an integrated system of robots is now being undertaken by some of the mid-size to large contractors who promote the development of systems that will substantially automate the construction of mid-to-high-rise buildings, and about a dozen of these systems are being deployed. Basically, they consist of a jack-up frame or push up jacks on which or below which a variety of robots for materials handling (e.g., cranes, hoists); fabrication (welding, cutting, finishing); and inspection are installed. The frame will have an all-weather enclosure to enable work to continue around the clock, at any season of the year. This framework will initially be positioned at the first of a series of repetitive floors to be built, and the robots will do about 30-70% of the work to construct that floor. Next, the whole frame jacks itself up to the next level,



1 Steel frame erecting robot
2 Steel frame welding/bolt tightening robot
3 Material transport robot
4 Fireproof spraying robot
5 Floor finishing robot
6 Robot to manipulate exterior wall board
7 Floor cleaning robot
8 Robot to manipulate wall board
9 Concrete placing robot
10 Interior finishing robot (spraying, painting)
11 Pipe embedding robot
12 Reinforcement bar erecting robot
13 Position controlling robot
14 Package transport robot
15 Security patrol robot
16 Duct cleaning robot
17 Floor cleaning robot
18 Piping system diagnosing robot
19 Exterior wall maintenance robot (painting, cleaning)
20 Exterior wall diagnosing robot
21 Window cleaning robot
22 Tank cleaning robot
23 Pipe inspection robot (gas, sewage)

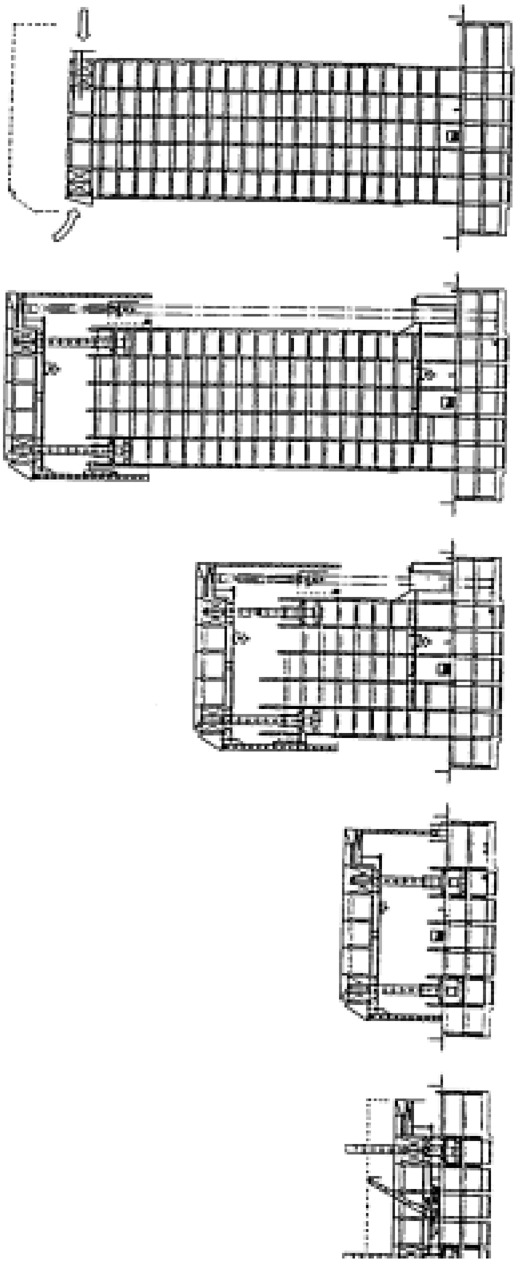
and builds another floor. The idea is somewhat like a slip-form for constructing a concrete structure, except that a whole building, not just a concrete structure, is 'extruded" from the system. This process continues until the building is done, then the automated components are removed, leaving the frame in place to become the structure for the top floor of the building.

The systems are in part motivated by an expected shortage of skilled labor in Japan, but over time will have economic and quality advantages similar to those of an automated factory. About 90% of present labor requirements will be replaced by automation. Those workers who remain will probably be highly skilled technicians who can program and maintain the robots. The systems provide for substantial integration of structural, mechanical, electrical and finishing operations that are used in the construction of a building. There are also obvious interfaces to and interactions with design. In this way they represent the computer-integrated-construction (CIC) systems of non manufacturing industries.

Impressive as such automated building systems will be, there remain many challenges facing the advancement of construction automation and the development of more capable construction robots. Perhaps the most difficult is that of developing the intelligent software to integrate future machines into the complex environment where they will work.

Before considering what should go into the core of construction robot software, it is important to think about some bounds on this software. Relative to the intelligence to support the successful execution of construction tasks and to the intelligence and human dimensions of a typical construction worker, we are still looking at a most rudimentary kind of "intelligence" to form the core of a construction robot's software.

In general, what is needed is some way of modelling within robot agents some feeling of their environment, such as key characteristics of objects and other agents, in ways useful for reasoning. We have to reduce the knowledge that needs to be encoded in machine systems a priori by enabling them to tap the vast knowledge sources in their environment when needed. This is extensibility, which some might call a simple form of machine learning. Robot societies or groups should be able to assemble knowledge and enlist other agents needed to perform a task and respond dynamically to change. Robot reasoning and control software should deal with unexpected obstacles, road



conditions, failure of a machine-positioning system, damaged material, improper tools, or imprecise instructions.

9. CAD-SR/ Service Robotics

9.1. CAD/AGV (Automated Guided Vehicles)

In order to use CAD information for future service systems and service robots we collected experience in the technical of AGV (automatic guided vehicles) concerning kinematics, navigation guidance control and design of a control of conditions. The kinematics of vehicles known for automatic movement on construction sites. Such a kinematics was developed by my center for technology transfer, but further alternatives should be worked out.

9.2. CAD/ SAFEMAID (Semiautonomous facade maintenance device)

Another promising application of CAD data into service systems and robotics is the field of half -respectively full-automatical maintenance of façades under different surface-conditions:

Fields of examination are:

- Height reaching devices
- Ergonomic investigation of facade maintenance
- Cleaning and maintenance methods of different facade surfaces
- Prerequisites for the use of automatic or telemanipulated facade maintenance devices
- Economics , serviceability
- Testing and control by simulation

Aim of the researching-efforts is the development of a semi-automatical façade-service implement for the maintenance and diagnostics of skyscraper- façades and other areas of building which are accessible from outside. The implement shall be programmable as well as navigateable by remote-control, and it shall be flexible concerning the tasks (cleaning, diagnostics by camera, maintenance, ...) and the use (suitability for buildings already existing).

Beside first studies concerning the pracability several computersimulations about possible kinematics and working-processes were worked out at the department.

10. CAD-TR /CAD-CSCW: TeleRobotics/Computer Supported Cooperative Work

Global AEC projects require a multi-designer and multi-construction-machine system which has a realizeability capacity. It also provides a cooperative creation environment from design activity to prototype construction, which is indispensable for product development and the predictive simulation of complex construction projects. The requirements, the necessary functions and the implementation of a "cooperative tele-designing and tele-construction system" which is distributed on a computer network . The necessary technologies which have been implemented for a cooperative tele-designing and tele-construction system using the Internet are as follows: (1) visual information display, such as predictive display of geometrical information to compensate for time delay and real-time construction assembly display using multiaxis force information, (2) predictive auditory information presentation using a physical model of block assembly and an information transformation technique, (3) predictive force information presentation, (4) tactile presentation of the state joining as high frequency vibration, and so on. The software system was implemented as a multi-construction -machine system. Necessary agents and their functions are discussed based on the system, as implemented and tested.

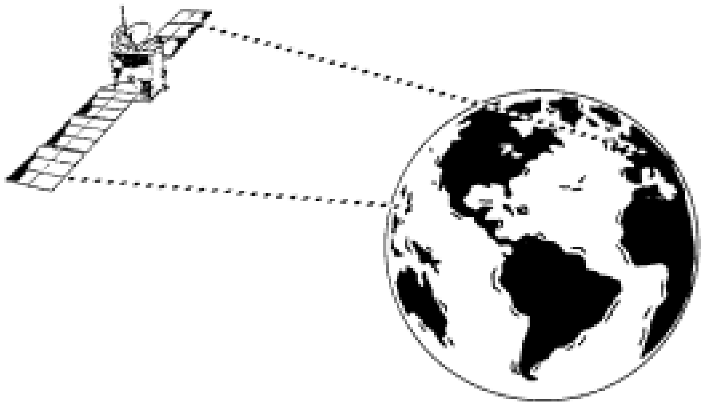
11. CAD/Integration of Intelligent Agents as the Missing Link.

The factory automation already reached a sufficient level of automation, but as for the on site environment, which is ill defined, unstructured and shape-changing, there may not be accurate correspondence of an agent's knowledge about the environment to its real state at any time. So we have to prefabricate as much as possible in the structured environment of factories and only realize the final assembly on-site. In future construction field environments, intelligent machines, like their human counterparts, will thus need to gather knowledge to plan and control autonomous tasks. Not only the robots, but most of the intelligent agents will need a unifying core of intelligent software and a framework for defining and communicating knowledge about designs and field operations in a way that can effectively be utilized for their production tasks.

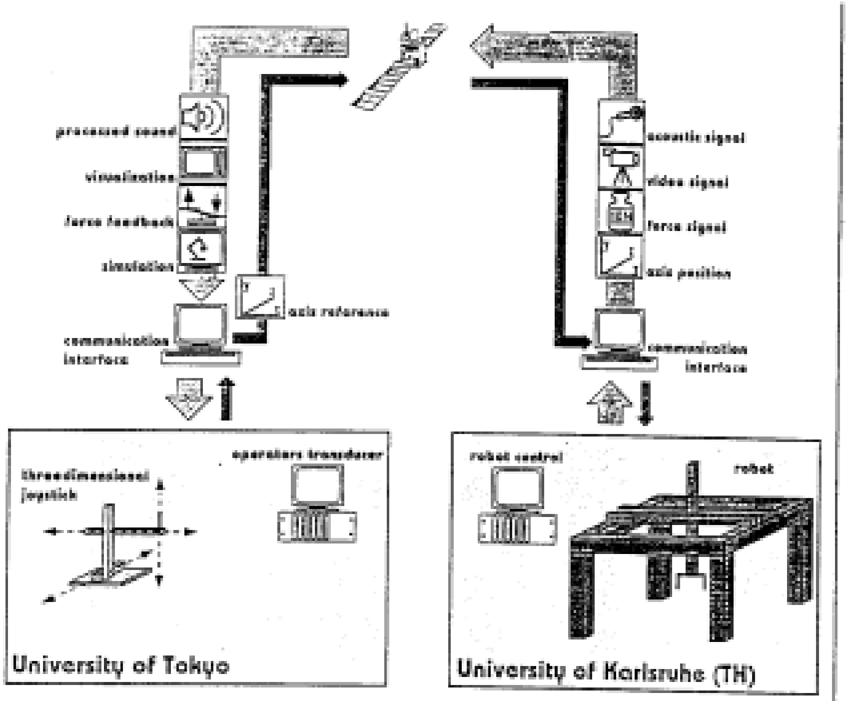
IMS
Intelligent Manufacturing Systems
International Conference on Rapid Product Development

Prof. Thomas Bock   Universität Karlsruhe (TH)

Inter World Intelligent Manufacturing System in Building Construction



- high precision and quality, three shifts per day
  Präzision und hohe Qualität, 3-Schicht-Betrieb
- favours the realization of an CIM-concept
  begünstigt die Realisierung eines CIM-Konzeptes
- efficient use of expert knowhow / simultaneous monitoring of more than one construction site
  Effektive Nutzung von Expertenwissen / gleichzeitige Überwachung von mehreren Baustellen
- further application: maintenance of supply installations (e.g. pipelines) in inaccesible areas
  Weitere Anwendung: Wartung von Versorgungs-einrichtungen (z.B. Pipelines) in unzugänglichen Gebieten



- reality sensation based on a predictive information display method
  Zustandsdarstellung durch prädiktive Simulation
- six-axis force / tork sensor
  Sechs Achsen Kraftmomentensensor
- fail safe system / force monitoring
  Störfallbehandlung / Kraftüberwachung

The future could be the construction knowledge environment, and some ways in which the core software of an intelligent robot might interact with the environment. The organizational context in which the robots might be working, the interfaces to computer-aided design (CAD) databases and reasoning, interactions with other field agents-both human and machine-and interfaces to knowledge sources in the world beyond the field.

In an environment of this type, all of the agents-both human and machine-could be working in the context of an integrated model-possibly one that may evolve from today's research on distributed databases and knowledge bases, object-oriented systems, constraint-based systems, neural networks and other advanced telerobotic computer science and engineering. In this context, from project conception through design and construction, and on into facility management and recycling over the life cycle of the project, the virtual model would evolve and change to accurately reflect the history, present state, and future plans for the facility.

The scope of research needed to build theories and core software to support integrated design, construction and facility management is huge. Each step in this research should lead toward a general architecture handling the knowledge agents need to function productively in a knowledge environment. The resulting software could then be extended by developers of applications-oriented robots to handle particular areas of expertise, whether in performing design, managing other machines, in doing specific physical tasks, or monitoring and controlling a facility's operation. The ultimate objective should be to design and develop the general theory and software core for machine agents which can then be embedded in agents specialized for particular tasks. Thus may evolve parallel virtual and physical models of our built environment, and intelligent agents who could work cooperatively to sustain our ecosystem.

Conclusion

It is clear that CAD technologies will continue to advance quickly in other industries. But what we need is how effectively the construction industry will adapt to and exploit this technology for its own advancement. If we do so successfully then we can cope with the structural changes that are now taking place in the construction industry. If CAD data will not only be used for designing and drafting but also for controlling the whole construction process, then we can stay competitive during the chaotic market conditions that lie ahead of us. Due to the fact that about 2/3 of the construction costs are decided during the design stage it becomes a strategic necessity to further process the CAD data for the efficient realization of the construction process.

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