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Automation and Robotics in Construction: Japanese Research and Development

by
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The U.S. Army Corps of Engineers' construction program needs to reduce costs and improve quality. Productivity is decreasing in the U.S. construction industry, which is the opposite of the manufacturing segment, where productivity is improving. One reason for this is the use of advanced computer and machine technologies. The introduction of advanced construction technologies is particulary evident in Japan.

This report presents information gathered during a study of the Japanese construction industry. Much of the information was gained through interviews with company representatives. Particular focus was placed on identifying the methodology and organization that the Japanese use in their research and development for automated construction systems, including development of robotics.

The information gathered shows that the Japanese are considerably ahead of other countries in their applied research towards construction automation. The organization and methodology that each Japanese company used toward this effort seem very similar. The differences between Japanese companies and their U.S. counterparts as they affect the introduction of new construction technologies are discussed.

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The U.S. Army Corps of Engineers' construction program needs to reduce costs and improve quality. Productivity is decreasing in the U.S. construction industry, which is the opposite of the manufacturing segment, where productivity is improving. One reason for this is the use of advanced computer and machine technologies. The introduction of advanced construction technologies is particulary evident in Japan.

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FOREWORD

This investigation was performed for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under project 4A162731AT41, "Military Facilities Engineering Technology"; Work Unit B0-042, "Advanced Technology Applications for Quality Assurance." The HQUSACE Technical Monitors were Robert Chesi and Richard Carr, CEMP-CE.

This study was performed by the Quality Assurance Team of the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USACERL). Frank W. Kearney is the Materials and Quality Assurance team leader, and Dr. Robert Quattrone is Chief of USACERL-EM.

COL Carl O. Magnell is the Commander and Director of USACERL, and Dr. L. R. Shaffer is the Technical Director.

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AUTOMATION AND ROBOTICS IN CONSTRUCTION: JAPANESE RESEARCH AND DEVELOPMENT

1 INTRODUCTION

Background

The U.S. Army Corps of Engineers' Military Construction Program needs to reduce costs and improve quality. There is a strong indication that productivity is decreasing in the U.S. construction industry. This is the opposite of trends in the manufacturing segment, where productivity is improving. One reason for this is the use of advanced computer and machine technologies.

The introduction of advanced technologies into the construction industry has been particularly evident in Japan.[1] Various types of robotics systems and other modes of automation have been applied to design and construction in an effort to improve quality, increase productivity, and reduce costs. The technologies that have been successfully used in Japanese manufacturing industries, such as automotive and electronics, are now being intensively researched for integration into the Japanese construction industry. The Japanese have been one of the leaders in this area due to the structure of the construction industry and contractor control of research and development[2] as well as the traditional reasons they have been successful in automotive, electronics, and other industries.[3]

The top five Japanese contractors differ from most of their American counterparts by operating research and development laboratories to develop new technologies for construction.[4] Governmental and other incentives provide a positive environment for transferring new technologies into the marketplace. Additionally, the Japanese contractor's organization is much more integrated across the various trades, thereby lowering resistance to these technologies. This study assesses state-of-the-art construction technology in Japan and provides a means of evaluating this technology's potential use and direction in the United States.

Objective

The main objective of this study was to examine the five leading Japanese construction contractors and identify the current status of their research and development methodology for introducing technologies into the construction industry. The following tasks were identified to reach this objective:

1. Identify the approach and methodology of each major Japanese contractor.

2. Develop company profiles to include project scope and administrative structure.

3. Analyze and compare methodologies and identify common patterns for research and development.

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[1] *International Symposium on Robotics in Construction* (Conference Proceedings 1984-1988, Carnegie-Mellon University, 1988).
[2] "Are They Better," *Engineering News Record* (March 3, 1988).
[3] D. O. Carlson, *Automation in Housing* (CMN Associates, Inc., June 1984).
[4] "Are They Better."

4. Identify trends and plans for introduction of new technologies in international and local industry.

This report is intended to provide a brief introduction to current conditions in Japan and identify patterns that may be beneficial in understanding current trends in the area of construction automation.

Approach

Information was gathered through interviews with company representatives and from published information. The two main focuses were on the structure of the research and development teams that were investigating automation in construction and the existing and planned work or areas of application that were identified as offering strong potential.

Mode of Technology Transfer

This report serves as the primary mode of technology transfer.

2 OVERVIEW OF THE JAPANESE CONSTRUCTION INDUSTRY

Robotic Development

The Japanese construction industry is a leader in introducing and employing robotics and automated technologies, and one reason is the structure of the industry. A few companies dominate Japanese construction. Essentially, these companies are design-build firms and manage all facets of the construction process; they have integrated responsibility for the whole construction process. By contrast, in the United States different organizations are separately involved in materials, equipment, construction, design, and so on. Japanese organizations use integration to achieve efficient utility of all construction materials and other resources and activities.

Development of robotized construction operations by the Japanese contractors can be subdivided thus:

1. First generation, using robotics technology to perform construction tasks whose manipulative requirements are within present capabilities;

2. Second generation, developing modular robotic elements that can be arranged to perform different tasks; and

3. Third generation, designing construction operations that require manipulative capabilities within the range of modular robotic elements.

Japanese contractors are working simultaneously in all of these areas. We may expect to see results in third generation applications within a couple of years. As the costs of robot technology decrease and its capabilities improve, economical feasibility of robotic construction will become a reality

Additional factors also contribute to Japanese leadership: Japanese expertise in manufacturing technology, acceptance in industry and labor of automated construction processes, government's attitude in assisting industries through regulations, and government's use of academic resources to assist the construction companies in research that is basic to the construction industry. Japanese companies are strongly supported by the universities and the government in their efforts to robotize construction operations.

One of the leading universities involved in researching robotics applications in construction is Waseda University. Researchers there are involved in the WASCOR (Waseda Construction Robot) project, whose purposes are to study robot construction of prefabricated homes, assembly of steel reinforcing bars for concrete, and concrete mold assembly. The government assists the construction industry by funding university studies and giving incentives to the construction companies. The level of these incentives is related to the companies' efforts in developing new and better construction technologies.

Each of the top five Japanese construction companies has its own research and development facilities for construction automation. This work is performed by a team that draws on many different departments within the company. Teams are made up of six primary disciplines: The team leader, usually a mechanical or industrial engineer, is assisted by architectural engineers, civil engineers, computer scientists, and electrical engineers. Most of the major contractors in Japan have completed applications studies, which are not made public and are considered classified by the originating company. These applications studies have categorized construction operations and identified construction processes that are most suitable for development of robotized or automated processes.

After these applications have been identified, the companies develop the hardware and software needed for the robotized or automated construction process. After the hardware configuration has been defined, the construction companies work with construction equipment manufacturers to build prototype equipment. The Japanese company that develops a successful system retains the rights to market that technology in Japan and internationally.

Also, legal issues that encumber development of automation and robotics in construction in the United States, such as contractor liability and mandatory adherence to building codes, are circumvented by the Japanese. In Japan there is an overt effort to enact specific legislation to accommodate automation and robotics in construction, but no such effort is under way in the United States. Further, codes in Japan are nationalized; those in the United States are based on model codes but vary from one region of the country to another.

Japanese Methodology for Construction Automation Research and Development

Japanese construction companies' answers to questions regarding methodology in researching and developing automated systems for construction revealed a general pattern. Each company had an interdisciplinary team that drew on other organizations within the company. These teams typically consisted of the personnel described above, although there were variations in numbers and combinations. A mechanical engineer usually acted as the research team leader because automated systems development involves the design and fabrication of machine prototypes.

Initially, each team analyzed construction operations to identify areas that showed the highest potential for robotization. Factors involving work-study criteria as well as labor-oriented issues were considered. Economics, quality control, and safety were also highly important in identifying potential applications. Once applications were identified and prioritized, further analysis was carried out regarding construction operation, the environment within which the operation took place, and other important factors. Once conceptualization of the robotized operation led to an initial concept for machine design, the team would begin actual design and specification of the new machine, often using available machinery in order to reduce development work. Construction companies frequently cooperated with an affiliated equipment manufacturer in this process to utilize its expertise and facilities for prototyping. However, only a few systems have gone through a complete cycle to marketing. In such a cycle, a machine with economic benefit would be built and marketed by an equipment manufacturer, while the construction company would own all rights to the actual use of the new process and earn royalties from equipment sales.

3 JAPANESE CONSTRUCTION COMPANY PROFILES

Introduction

The major sources of new Japanese construction technologies are the in-house research and development facilities of each major contractor. Unlike the United States, most of the construction in Japan is performed by a few very large firms, which channel millions of dollars annually into research and development. Five of the top contractors in Japan are Taisei, Shimizu, Kajima, Takenaka Komuten, and Ohbayashi Gumi.

In addition to these firms, there are also the industrialized housing manufacturers. In contrast to the largest industrialized housing manufacturer in the United States, which produces around 15,000 units annually, the Japanese firm Sekisui Home produces approximately 35,000 units annually. Three other major housing manufacturers in Japan also outproduce the largest manufacturer in the United States: Misawa, Daiwa, and National House. Like the major Japanese contractors, these industrialized housing manufacturers devote millions of dollars to research and development. Their manufacturing facilities utilize state-of-the-art computer-aided design/computer-aided manufacturing (CAD/CAM) and robotics technology. By using the expertise developed in the automotive industry, The Japanese industrialized housing manufacturers have leapfrogged all competitors.[5]

Although automation and robotics have already proven to be economically viable in housing manufacturing, the experience of the major Japanese contractors in this regard has been less successful. One of the common views of adopting automation and robotization by United States contractors is, "Show me it's economical, then I'll use it." In Japan, however, millions of dollars are spent on research and development to automate and robotize construction operations, despite the fact that most of the systems developed are not paying for themselves. This is because Japanese contractors see automation and robotics as a key to productive construction technology in the future and plan to be the leaders in its use when that time comes.

Taisei Corporation

The largest research and development budget is spent by the Taisei Company. The Taisei Research Institute, shown in Figure 1, was recently budgeted at approximately $60 million annually. Taisei's administrative structure is shown in Figure 2 and the organization of the technical research institute is shown in Figure 3.

Taisei is the largest contractor in Japan and generates about $5 billion worth of projects annually. About one-third of these projects are civil works, and the remaining two-thirds are for building construction. The company performs a variety of construction tasks and was the leader in prefabrication with the development of the layered construction system.[6] Taisei is involved in prefabricated residential construction and has developed a new aerated concrete and wood building system. Residential construction makes up about 4 percent of its gross building projects. Taisei's technical research institute, shown in Figure 1, is staffed by about 200 researchers, with about 100 support staff members. They conduct a variety of tests on materials, structures, earthquakes, and construction techniques for both building construction and civil works.

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[5] D. O. Carlson.

[6] *Taisei Today* (Taisei Corporation, undated).

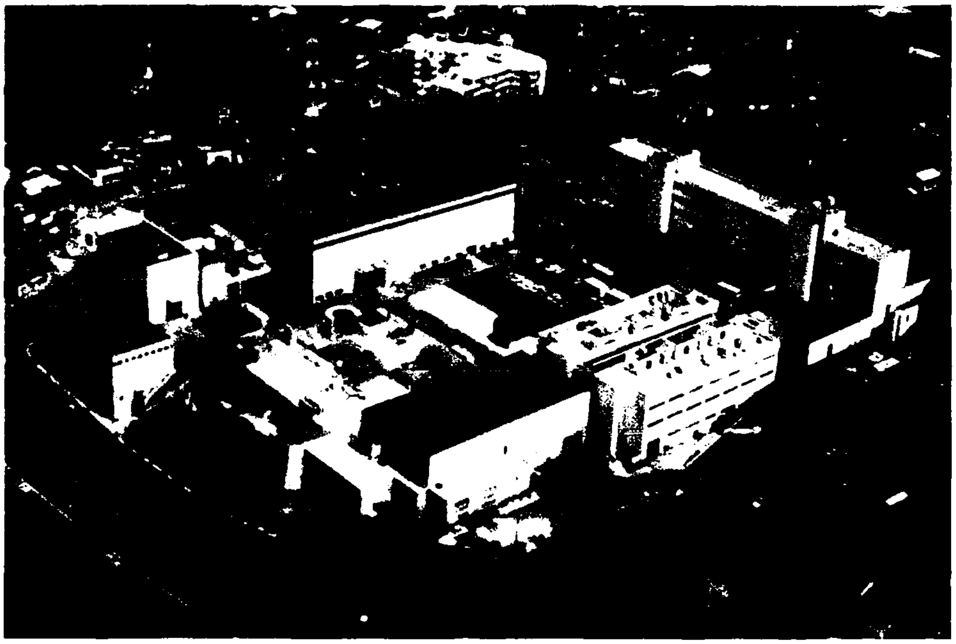

Figure 1. Taisei Research Institute. (Courtesy of Taisei Corporation)

Taisei has built many new and innovative construction projects, such as the world's first undersea sewage disposal plant, and it is doing pioneering work in the development of abrasive water jet cutting for steel, concrete, and rock. The company is also researching new tunneling techniques that are founded on the New Australian Tunneling Method (NATM), developed by the Army Corps of Engineers. It has developed computer control for shield tunnel boring, robots for spraying concrete, and is developing software for robotized horizontal concrete distribution. Taisei has developed the spraying robot shown in Figure 4. This robot follows tracks designed into the building. Originally, the robot was used to paint the exterior surface. Now, it is being used to clean and repaint the surface. Taisei has also developed a tile inspection robot (Figure 5). This robot climbs the walls and taps on the tiles, listening to the acoustic vibrations to determine if any tiles have exfoliated. Another recent robot is the wallboard manipulator (Figure 6). This human-controlled robot will assist in the pickup and placement of a sheet of wallboard. Taisei research studies for future robotic applications include concrete coatings, concrete finishing, on-site placement of building components, and on-site steel frame painting. Taisei developed a pillar-coating robot that was used in the construction of the IBM pavilion at the Tskuba Exposition in 1985. This robot was provided with a programmable controller and various types of sensors, and it would climb up to 50 m on a pillar and complete the finished coating work. According to Taisei representatives, research to automate construction operations is motivated by the desire to eliminate dangerous tasks and hazardous environments and to increase productivity and quality while lowering costs.

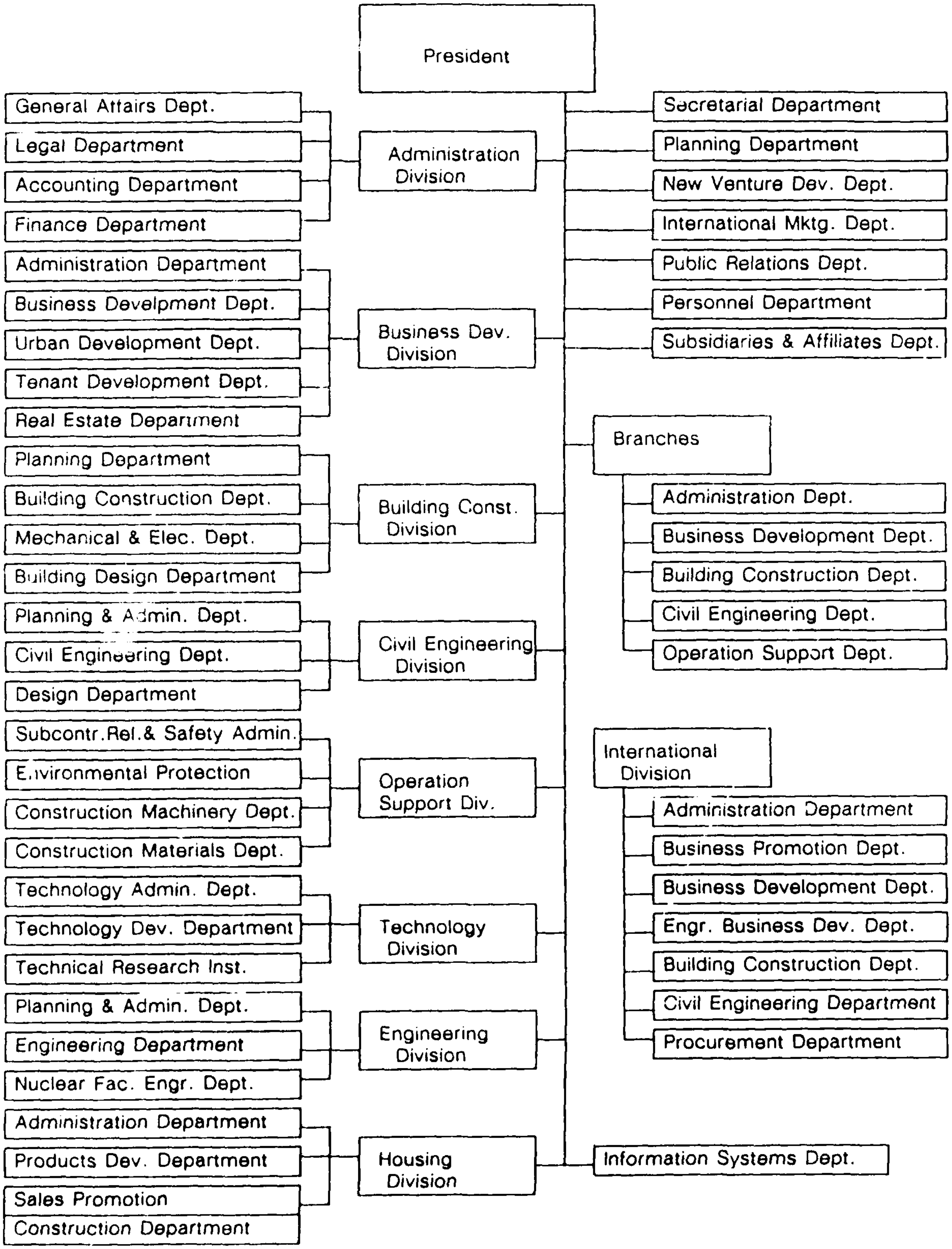

Figure 2. Taisei administrative structure.

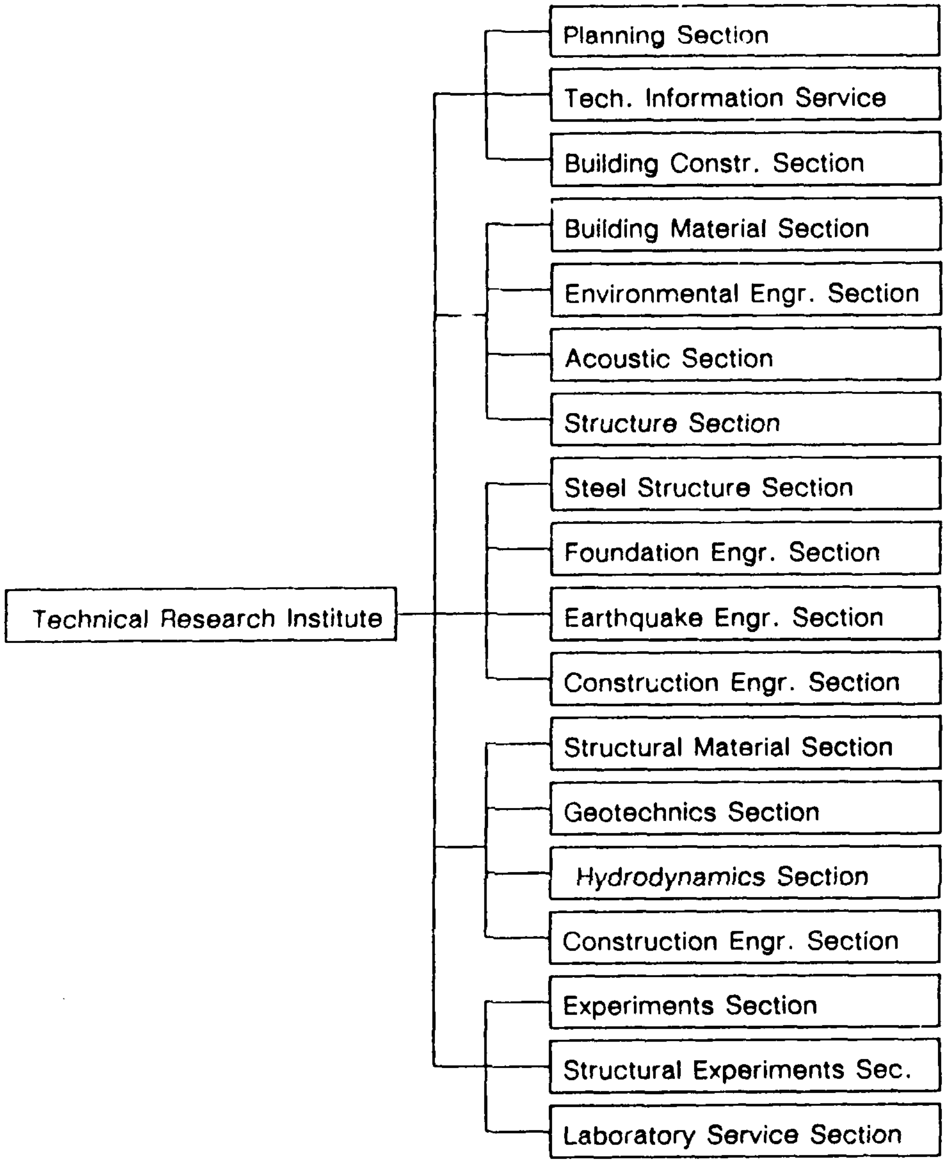

Figure 3. Taisei technical research organization.

Shimizu Corporation

The second largest Japanese contractor is Shimizu, whose annual gross revenues are around $4.5 billion. Its organization chart is shown in Figure 7. Its research facility is called the Shimizu Institute of Technology, and is organized as shown in Figure 8.

The company is very diversified and has constructed civil works such as bridges, tunnels, underground storage facilities, nuclear power plants, and ocean structures in addition to typical building projects such as offices, airports, and shopping centers. The company's international projects consist of approximately 15 percent of this total. Over 200 people perform R&D activities at Shimizu's research facility. Studies in structural analysis, CAD, earthquake engineering, nuclear waste disposal, and ocean platforms are among the ongoing research projects.

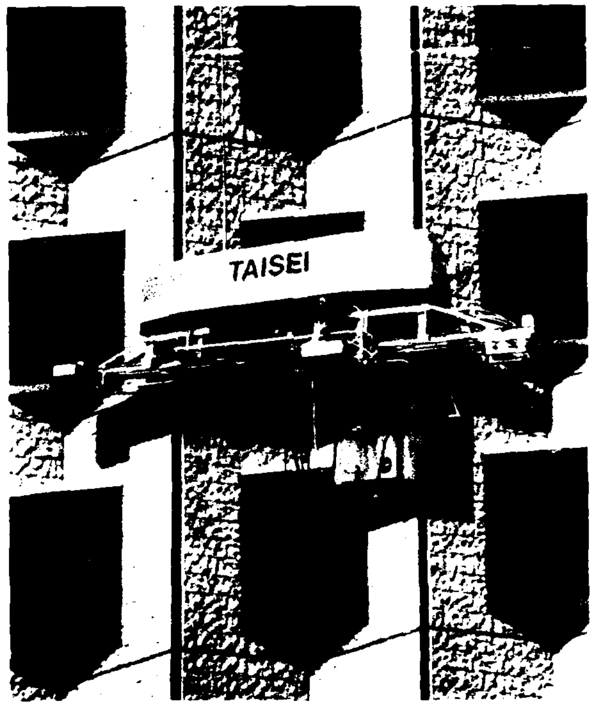

Figure 4. Taisei spraying robot.

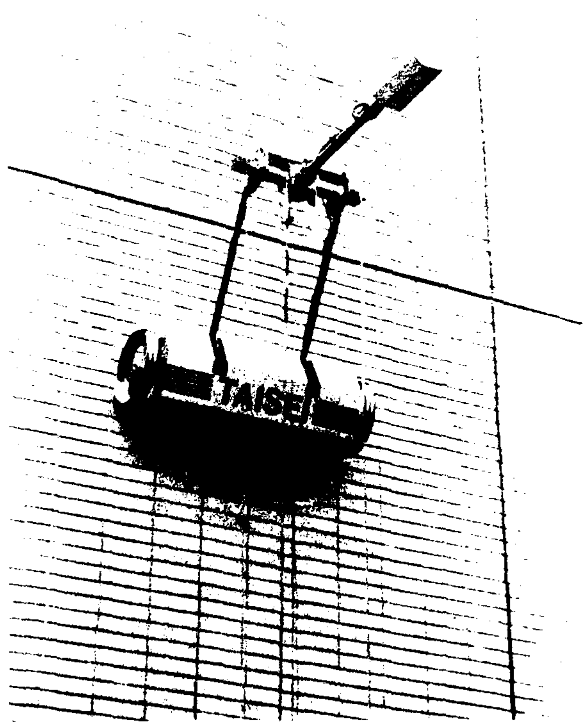

Figure 5. Taisei tile-inspection robot.

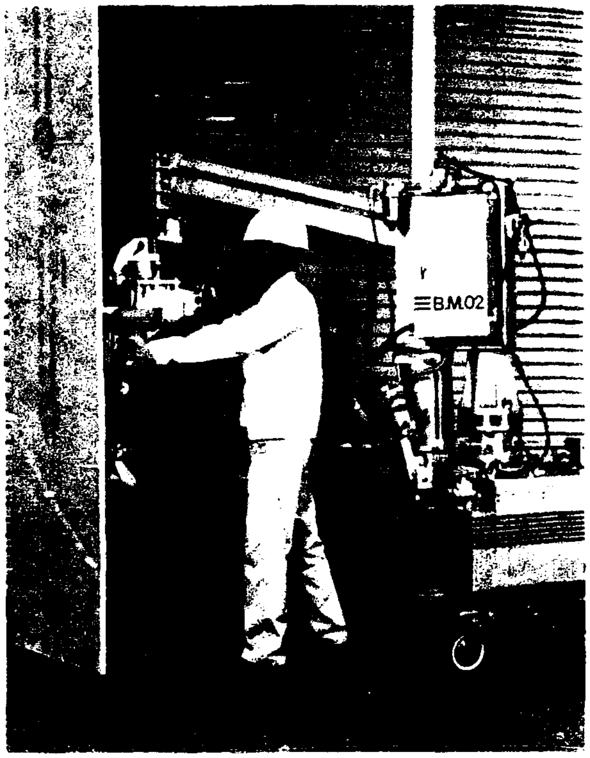

Figure 6. Taisei wallboard manipulator robot.

Shimizu developed the first true application of robots in construction with the development of the fireproofing robot shown in Figure 9. This robot sprays rock wool and cement slurry mixture onto structural steel in high-rise buildings. The original version shown here used a guide wire and followed the path that was laid out. It used sensors in its arm to locate beams and then apply the insulation material. The robot consisted of a Tralfa paint-spraying robot from Norway that was mounted on a mobile platform designed and constructed by Shimizu. The current version of this system is the SSR-3 (see Figure 10). In this system, the robot is given the configuration of the beams and girders as well as its starting position. It then generates the path and motions to perform the task without further intervention. Several improvements over the original version have been implemented to improve productivity, including the ability to spray continuously while repositioning for the next segment of the work.

One of the recent robotic systems developed by Shimizu is the concrete-finishing robot (see Figure 11). This robot demonstrates the latest concept in construction robotization-modularization of robot functions. This system consists of two separate modules: the mobile module and the finishing module. The finishing module is shown in Figure 12. This concept is an extension of flexible manufacturing systems, where in the mobile module can be utilized by some other process-specific module, thereby increasing flexibility by allowing it to be used with other processes. As will be shown later, this system follows directly from work done in the WASCOR project.

Other construction projects under development at Shimizu are concrete cutting, painting, steel lifting and positioning, and industrial cleaning. Future planned applications include a modernization of the beam-fireproofing robot as well as the following: concrete operations, steel framing, panel and curtain wall assembly, civil structures, excavation, and roller compacted dam.

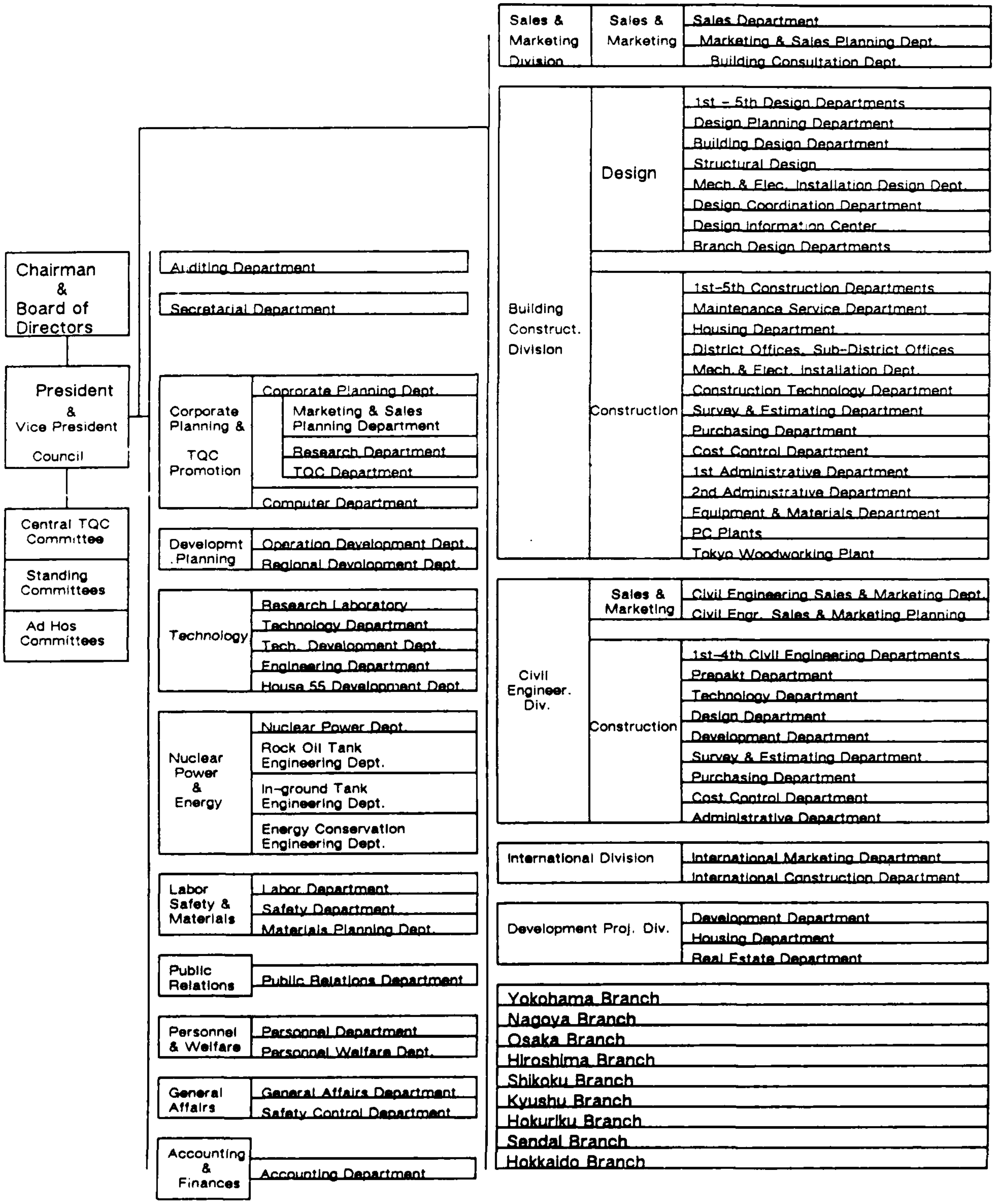

Figure 7. Shimizu organization chart.

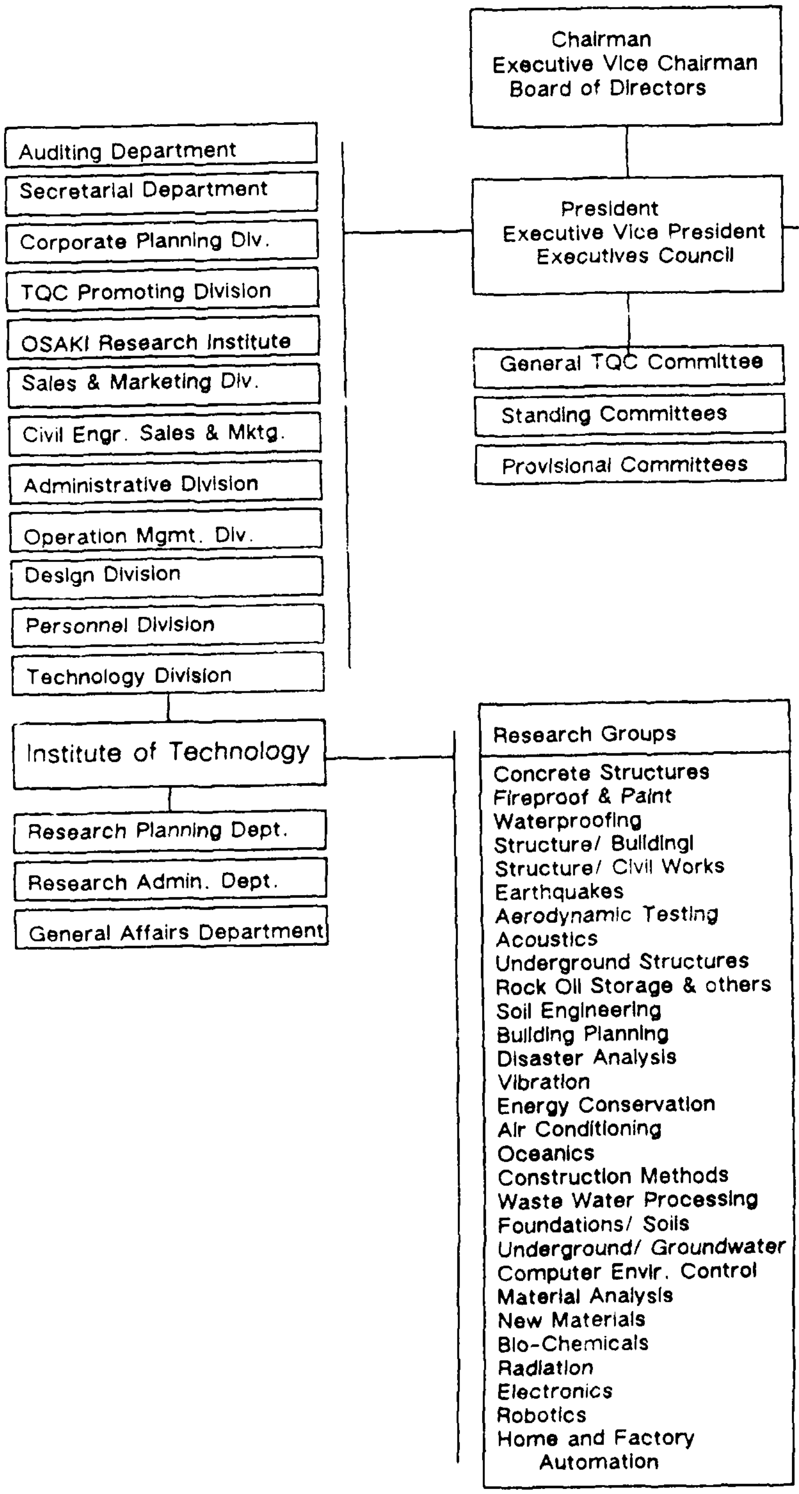

Figure 8. Shimizu Institute of Technology organization.

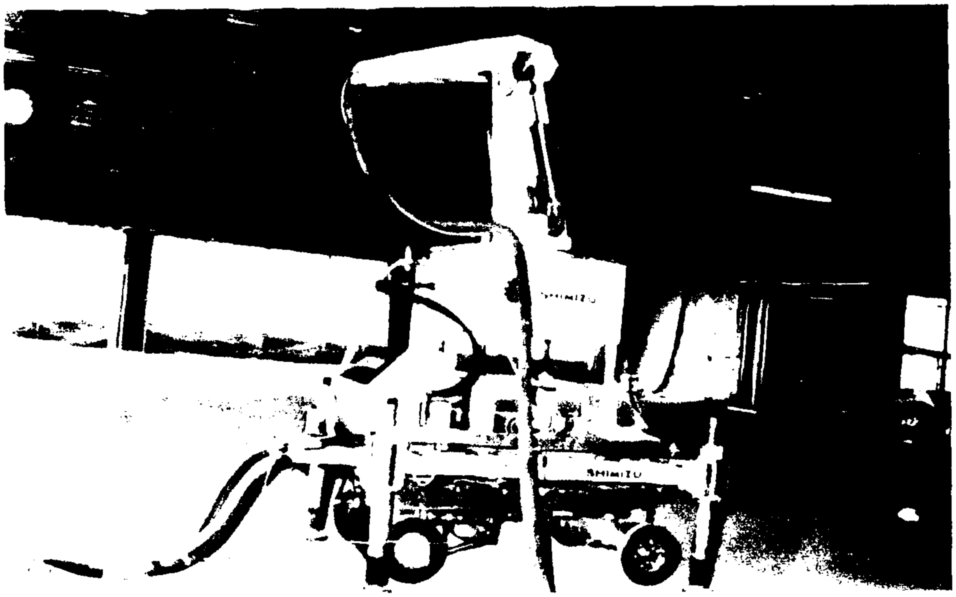

Figure 9. SSR-1 Shimizu spray robot.

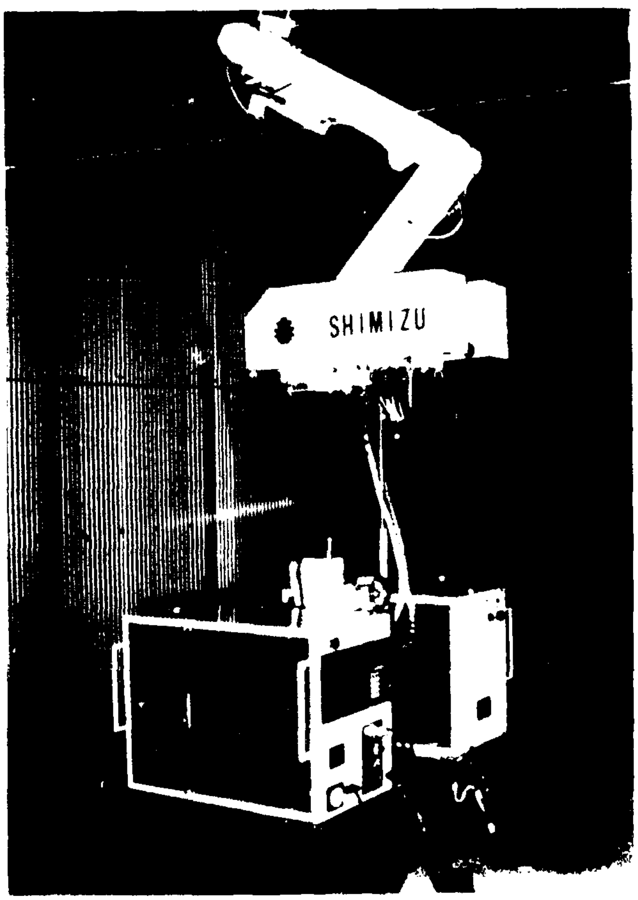

Figure 10. SSR-3 Shimizu spray robot.

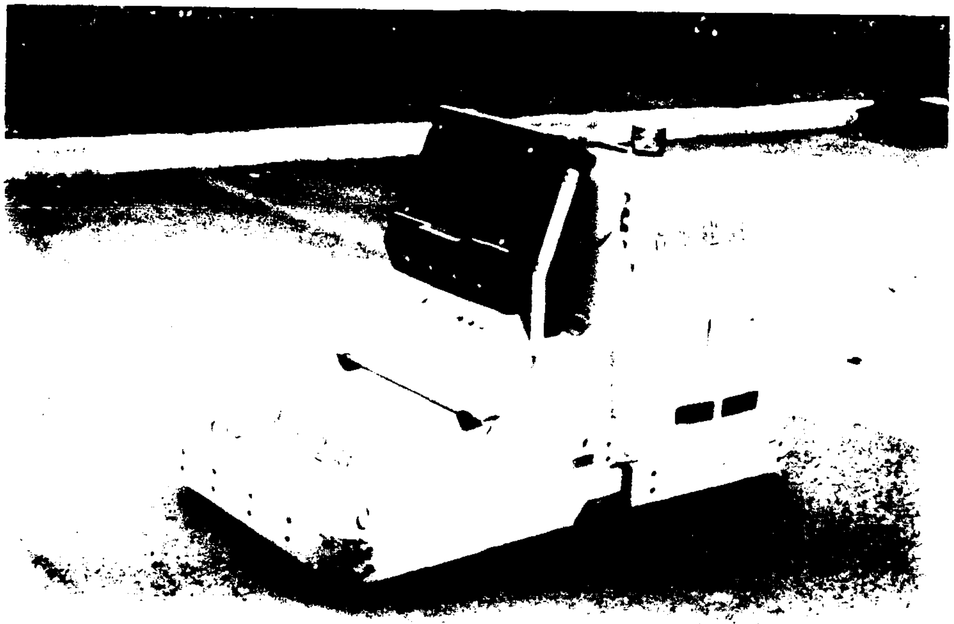

Figure 11. Shimizu concrete finisher.

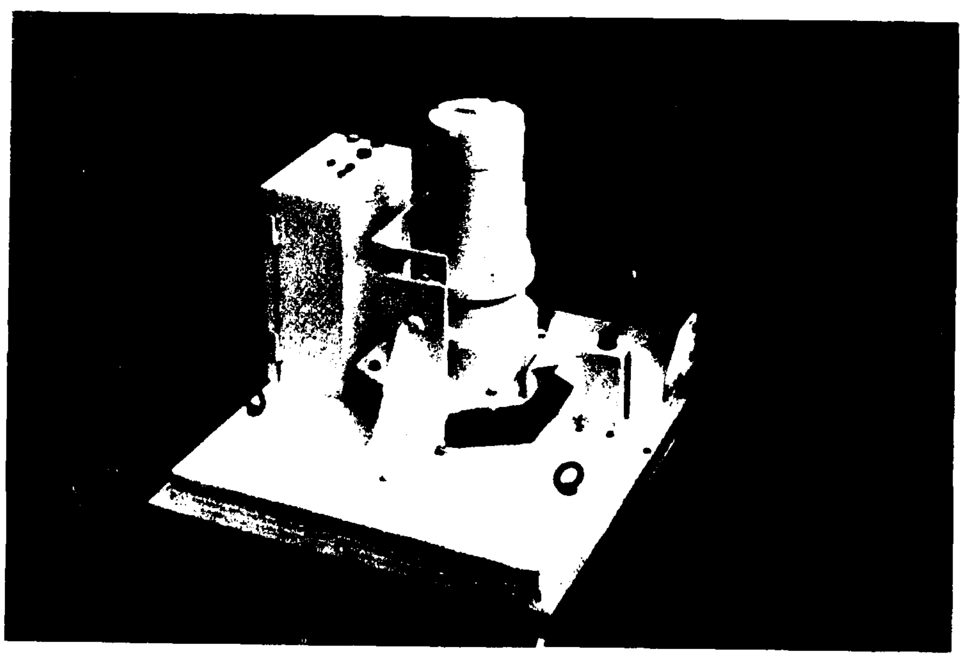

Figure 12. Shimizu concrete-finishing module.

Kajima Corporation

The Kajima construction company has annual gross revenues of approximately $4 billion. Almost two-thirds of their projects are architectural works, and the remainder are civil works. Their projects include dams, office buildings, oil storage tanks, manufacturing facilities, chemical plants, and power plants. About 10 percent of their projects are overseas, and the company plans to increase that figure.

Kajima's research facility staff numbers about 360 and includes 230 researchers in structural, mechanical, electrical, environmental, soil, hydraulic, geological, and chemical engineering. The facility's annual budget is about $15 million.

Development of construction robots at Kajima is performed independently by the company's researchers and jointly with robot manufacturers. This approach has allowed accumulation of technological knowledge and resulted in numerous robot systems. The first system shown (Figure 13) is a robot for tunnel construction. This large robot memorizes excavation patterns and plays them back with high accuracy and speed. The second system developed by Kajima is the re-bar-placing robot shown in Figure 14. This robot is used to place the great number of large-diameter reinforcing bars that are required in nuclear power plant foundations. The robot carries 20 bars and places them in either radial or staggered patterns.

The third robot system (Figure 15) was developed to inspect building tiles for defective installation. The robot moves along the exterior wall surface by means of a movable hanging section which is installed on the rooftop. The robot taps each tile with a small hammerlike device and captures the audio response. This signal is analyzed for any exfoliations, and if the tile is defective, the location is recorded for later repair.

Kajima's concrete-finishing robot shown in Figure 16. This robot performs the troweling operation on a concrete floor after pouring and leveling are completed. It is equipped with a gyrocompass and a distance sensor so it can navigate automatically. The mobile section moves over the surface while the arm swings the troweling paddle back and forth over the surface. It is capable of reproducing the same quality as that of skilled workers.

The Kajima company has robotized shotcrete operations and abrasive jet cutting of concrete, and its future plans include steel framing, demolition, pressure joint re-bar, and further shotcreting development. The decision criteria that Kajima uses in determining which applications to select are economic payback, safety, and quality.

Ohbayashi Gumi Corporation

Ohbayashi Gumi is a major Japanese contractor with annual sales of over $3 billion. Two-thirds of its projects are building construction, and the remainder is civil works. The research facility of Ohbayashi Gumi is the home of what company representatives say is the world's most efficient building: the Ohbayashi Research Institute. It is organized as shown in Figure 17.

The robotic applications developed at Ohbayashi Gumi include the auto clamp (see Figure 18) for the erection of steel columns and a so-called mighty clamp for the erection of steel beams.

The auto clamp allows the automatic remote release of the steel column after it has been moved into position by a crane. The device is remotely controlled and operates on an FM frequency. Figure 19 is a close-up of the clamp. Conceptually, this device acts as the end effector of the robotic system. It is combined with the other steel member placement mechanism, the mighty clamp, shown in Figure 20.

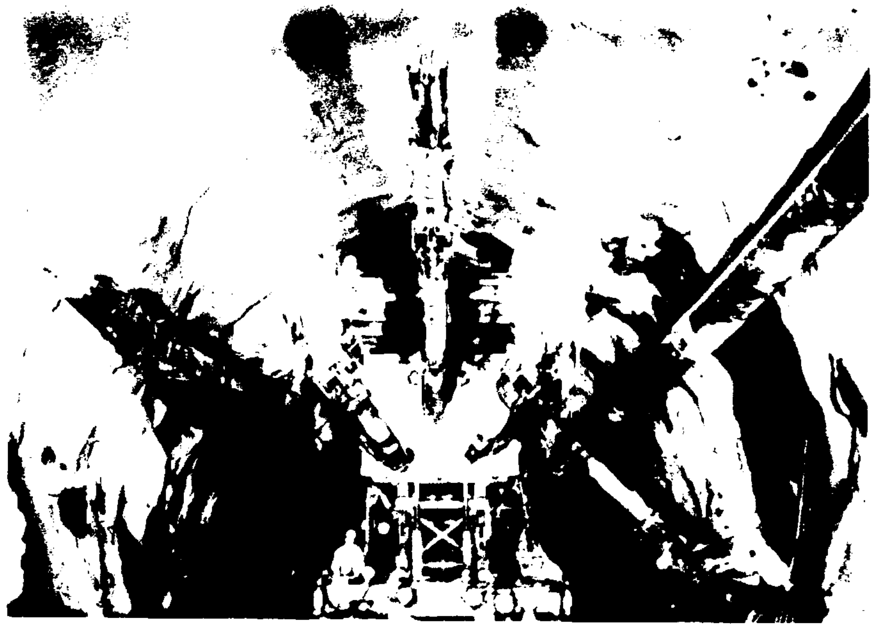

Figure 13. Kajima tunnel robot.

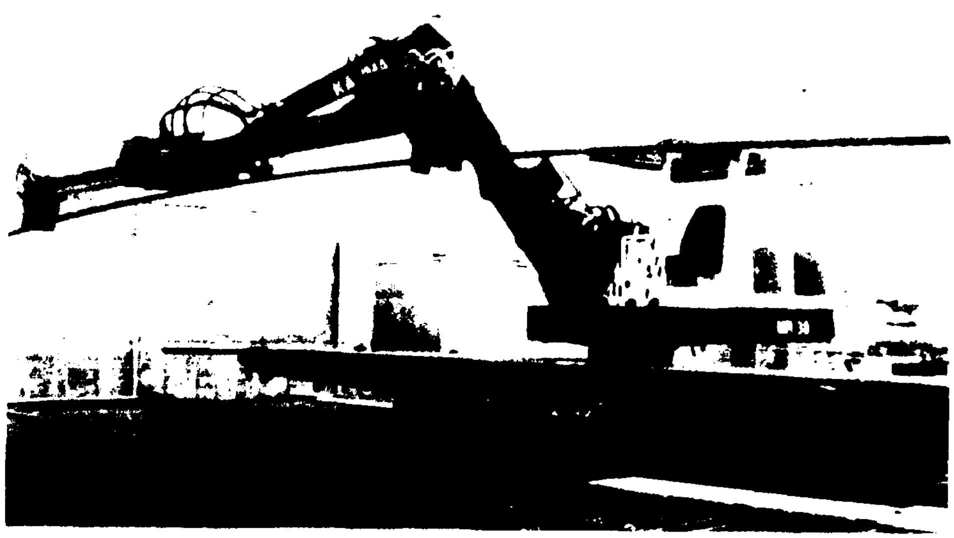

Figure 14. Kajima re-bar-placing robot.

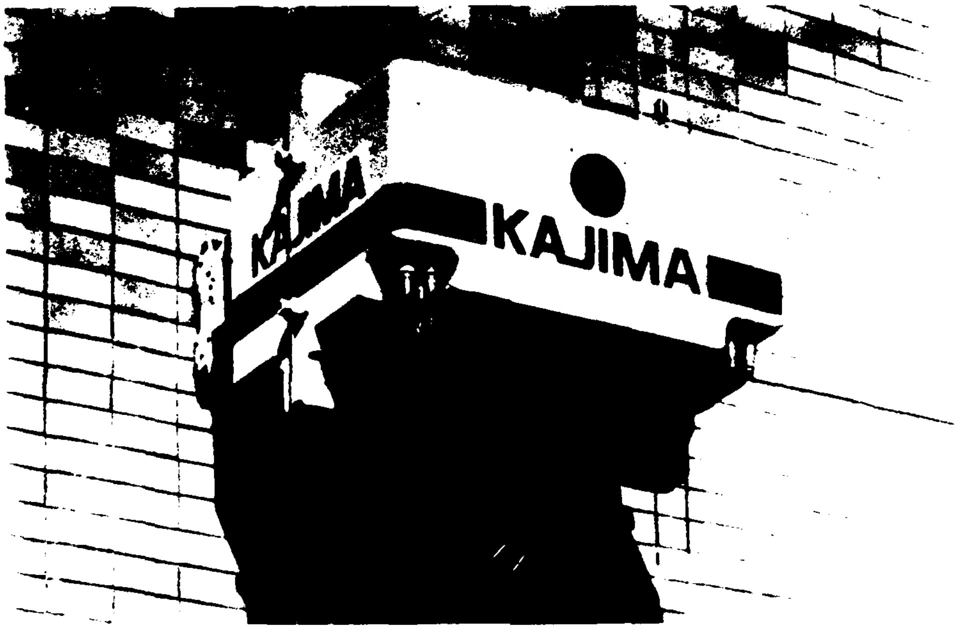

Figure 15. Kajima tile-inspection robot.

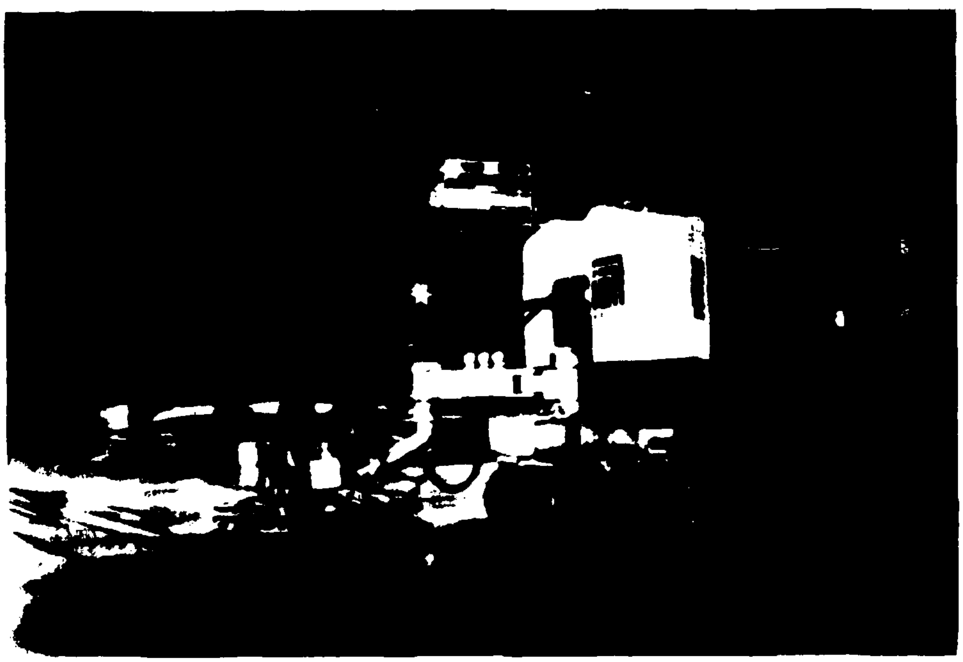

Figure 16. Kajima concrete-finishing robot.

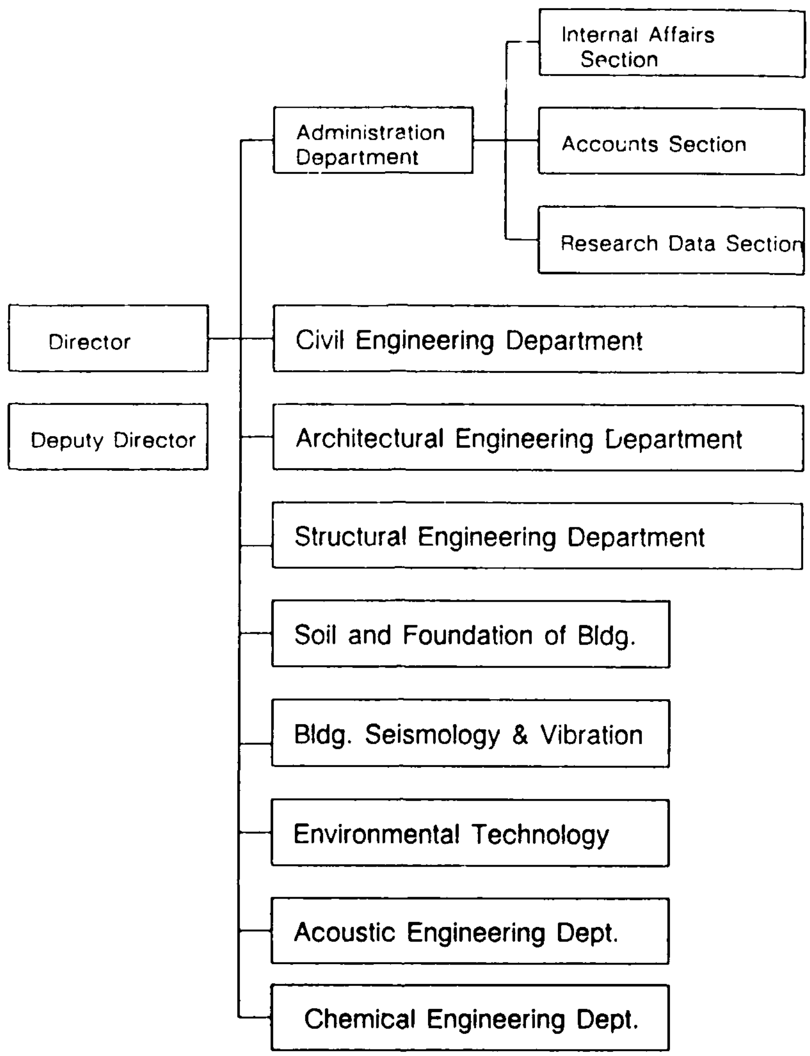

Figure 17. Ohbayashi Research Institute organization.

Figure 20 shows the clamp as it positions the steel beam. In Figure 21 the clamp is shown handling two beams for placement, thereby eliminating a complete fetch cycle. The device sits on the columns while positioning the members below. The columns indicate the high level of prefabrication that is performed in Japanese steel framing. Figure 22 shows the completed operation.

These clamps will be integrated with a robotized placing system similar to the placing crane shown in Figure 23.

This crane has five axes of articulation and can be used either as a concrete distributor or as a placing crane. When used as a placing crane, it can move various materials, such as concrete forms, steel framing, and reinforcing bars, around the work site. The crane is built on a fixed tower, which can be raised as high as five floors, to eliminate repetitive tear down and reassembly during construction.

Ohbayashi Gumi's plans for future applications include site automation, concrete leveling and finishing, re-bar placement, and steel frame erection.

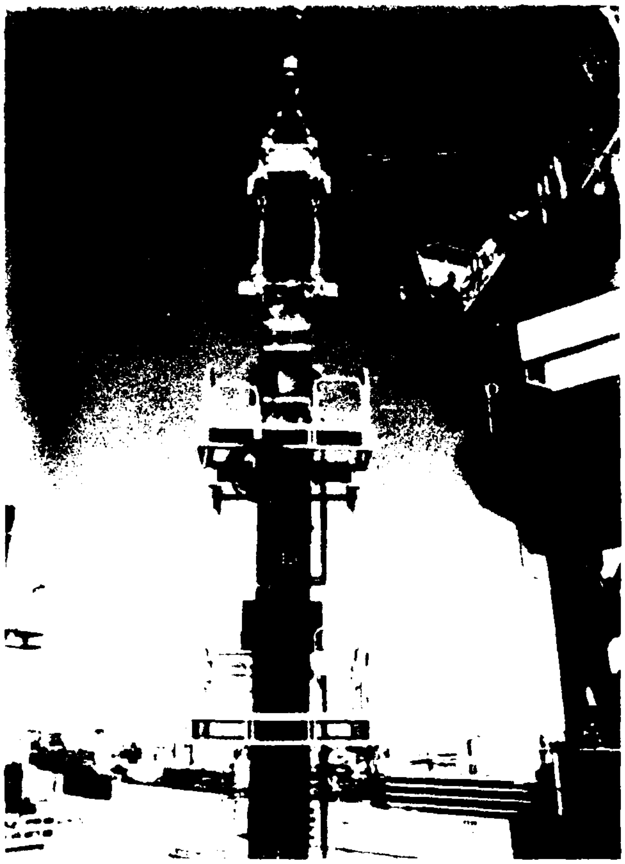

Figure 18. Ohbayashi Gumi auto clamp.

Takenaka Komuten Corporation

Takenaka Komuten has annual sales of over $3 billion. The company's organization is shown in Figure 24. Takenaka has expanded international operations, along with Kajima and Shimizu, with offices in the United States and other countries. The company's research facility is called the Takenaka Technical Research Laboratory and employs approximately 300 people. The organization of the research facility is shown in Figure 25.

Takenaka is in the process of developing a concrete placement and finishing system, and is presently automating the horizontal concrete distributing robot, shown in Figure 26 and developing algorithms for automatic column collision avoidance. Also under development are systems to automate the initial compaction and leveling of concrete. Takenaka has developed two types of robotized cranes, one similar to that developed by Ohbayashi Gumi and another that is very similar to a tower crane. The tower crane system as shown in Figure 27 is basically a very large manipulator that is mounted on a cylindrical, mobile base.

It has a vertical arm with a 10 m working radius and a 15 m vertical travel distance. It has 6 degrees of freedom and is capable of lifting 150 kg. This crane is used in re-bar placement and is taught the location of the materials and the location of the placement. The control system

Figure 19. Ohbayashi Gumi auto clamp closeup.

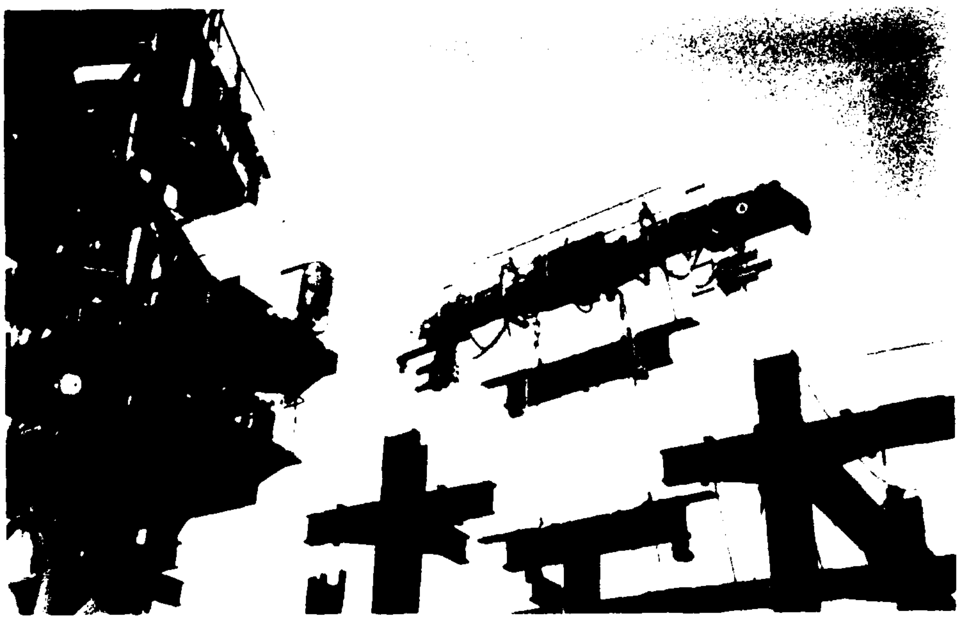

Figure 20. Ohbayashi Gumi mighty clamp positioning a steel beam.

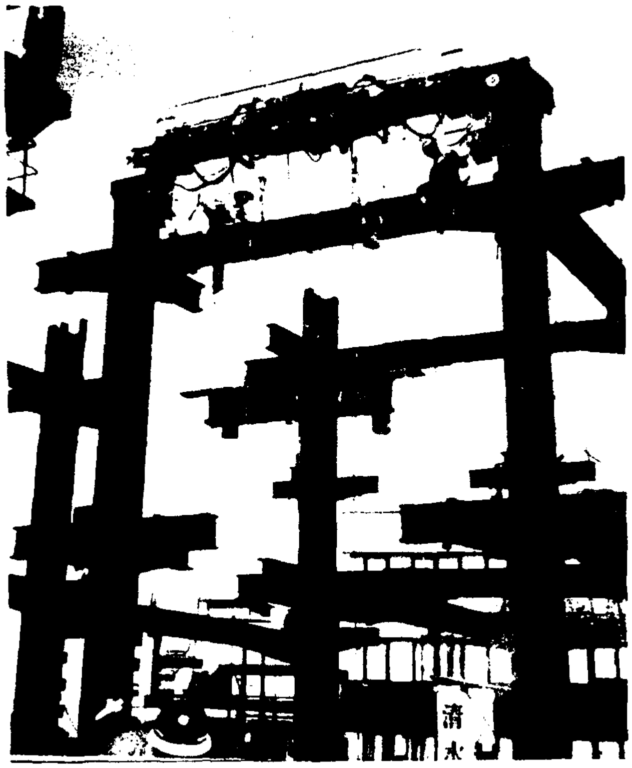

Figure 21. Ohbayashi Gumi mighty clamp handling two beams.

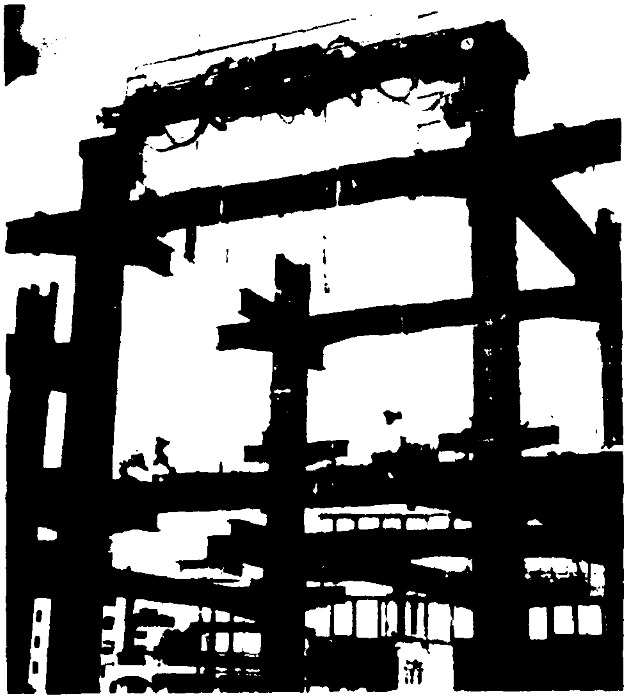

Figure 22. Ohbayashi Gumi mighty clamp after the completed operation.

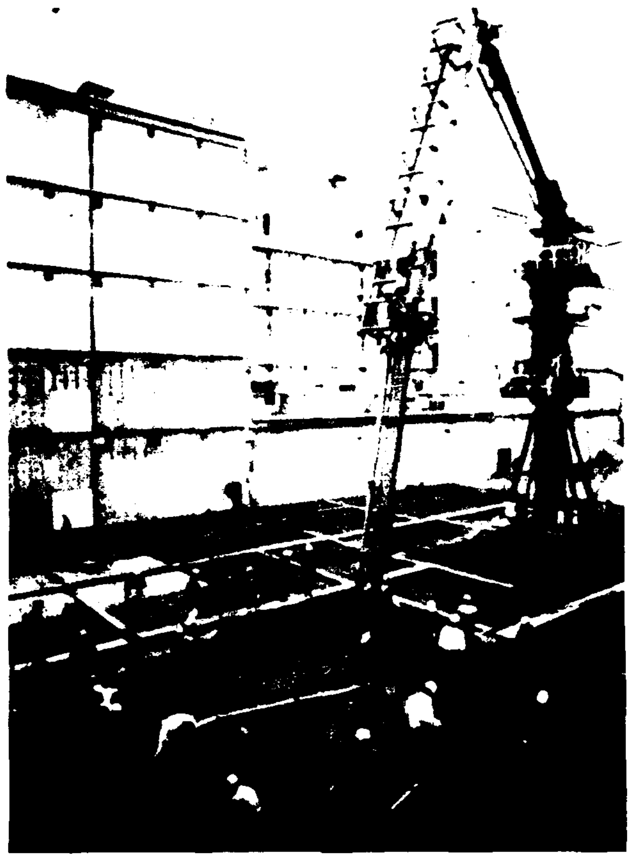

Figure 23. Ohbayashi Gumi condis crane.

automatically changes the placement position after each subsequent operation. This device has reduced manpower requirements by 60 percent. Relocation of the crane can be accomplished within 1 hr.

Takenaka has developed a tile-inspection robot very similar to the one developed by Kajima (Figure 28). Its operation is very similar to that of Kajima's tile-inspection robot.

Recently, Takenaka announced that commercial production of its newly developed concrete finishing robot would begin. This is the first significant application to complete the full research and development cycle. Takenaka plans on integrating this robot with its prototype concrete screeding robot which uses laser leveling to attain accurate screeding operations.

Shotcrete and tunneling applications have been developed, and future plans include structural steel assembly, horizontal concrete distribution, re-bar prefabrication and assembly, and floor finishing.

Industrialized Housing Manufacturers: Misawa Company

Taisei is the only major contractor for civil works and commercial buildings that performs residential projects. Automated residential construction is primarily undertaken by a few of the industrialized housing manufacturers. Although there are five major industrialized housing

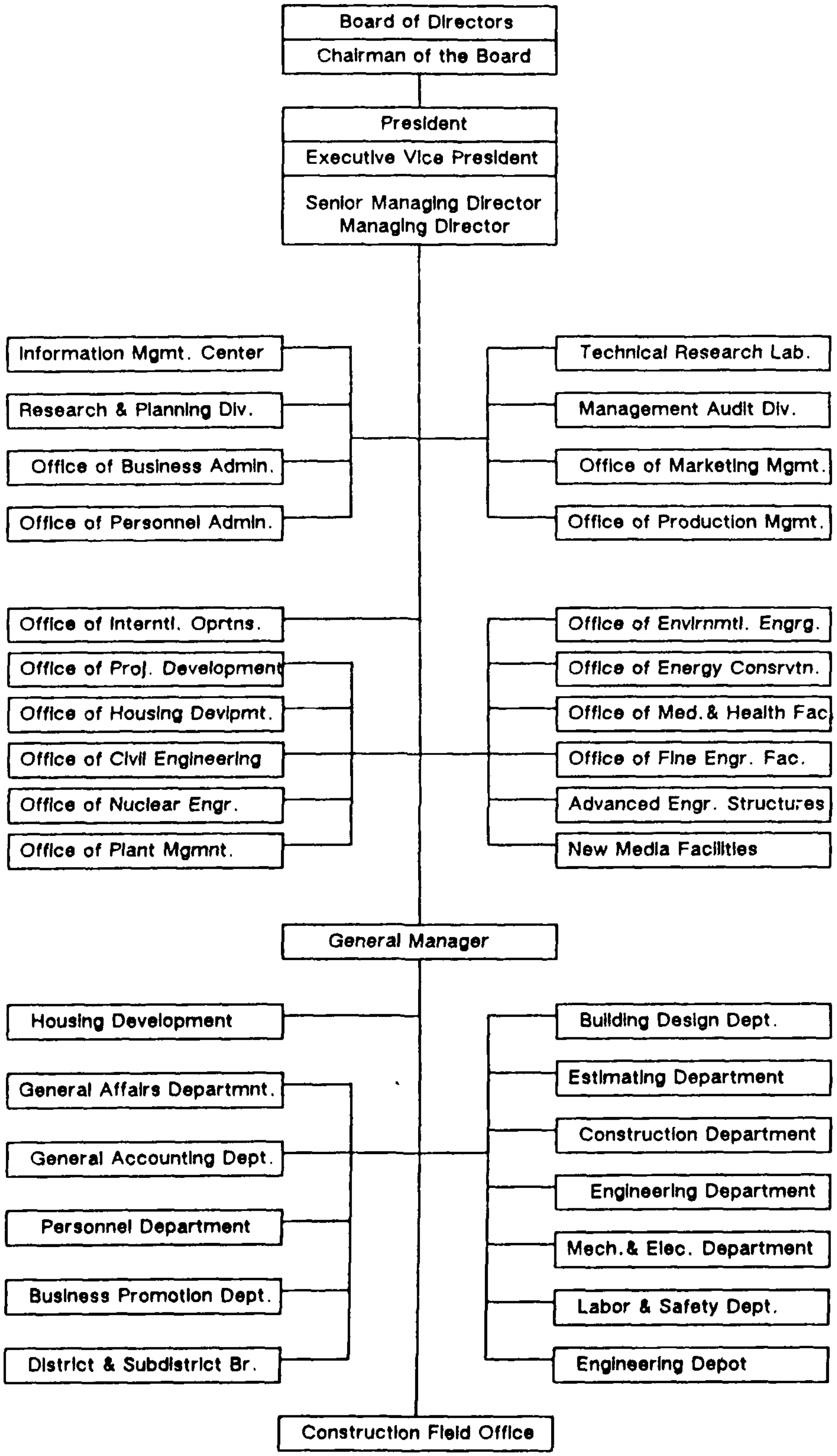

Figure 24. Administrative organization of Takenaka Komuten.

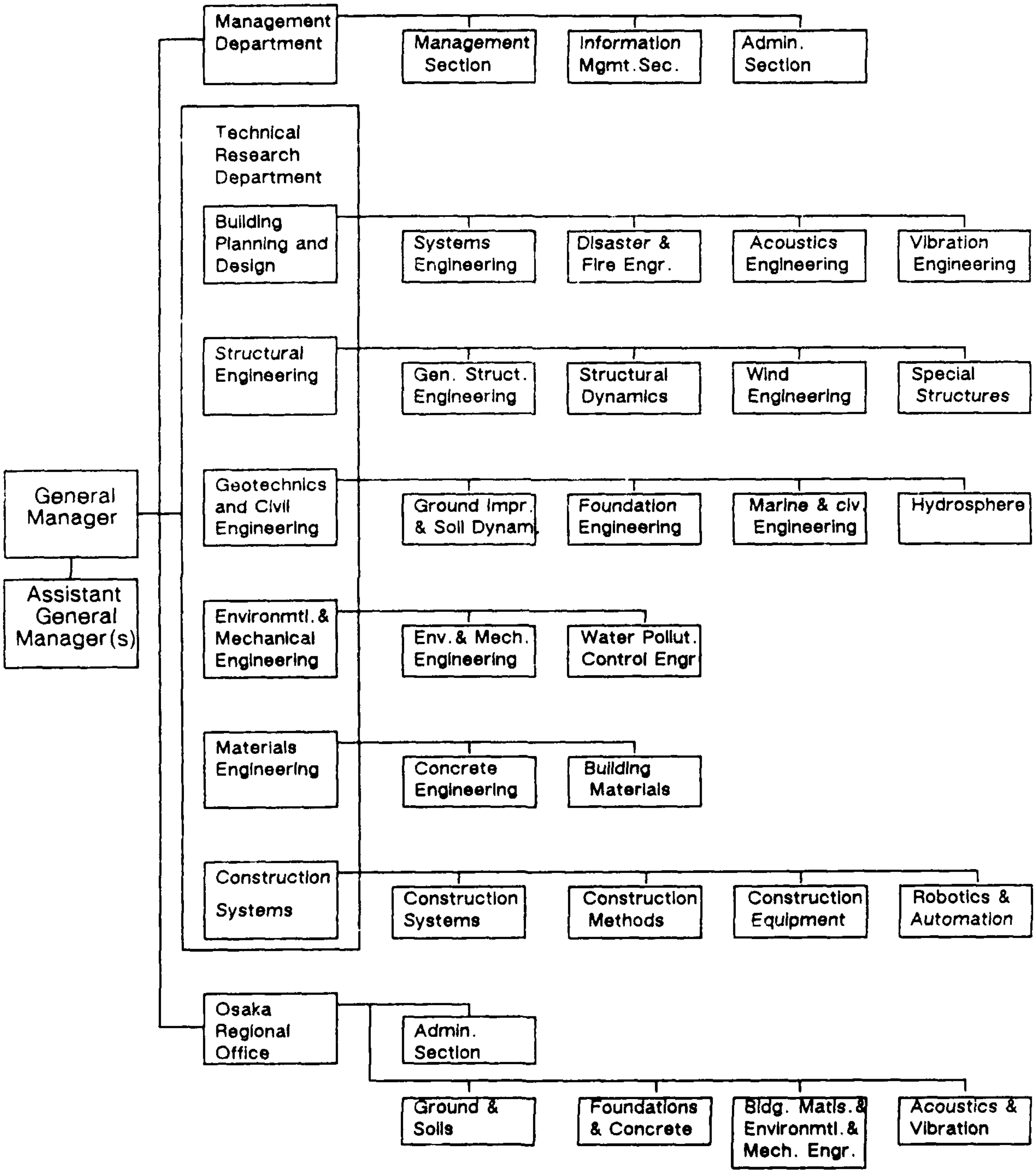

Figure 25. Takenaka technical research organization.

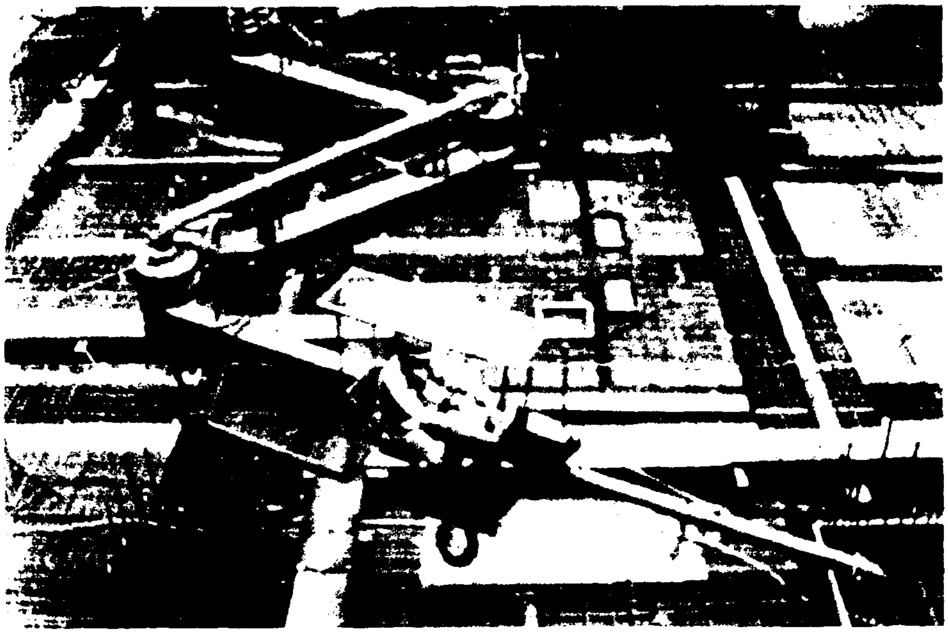

Figure 26. Takenaka Komuten concrete placement.

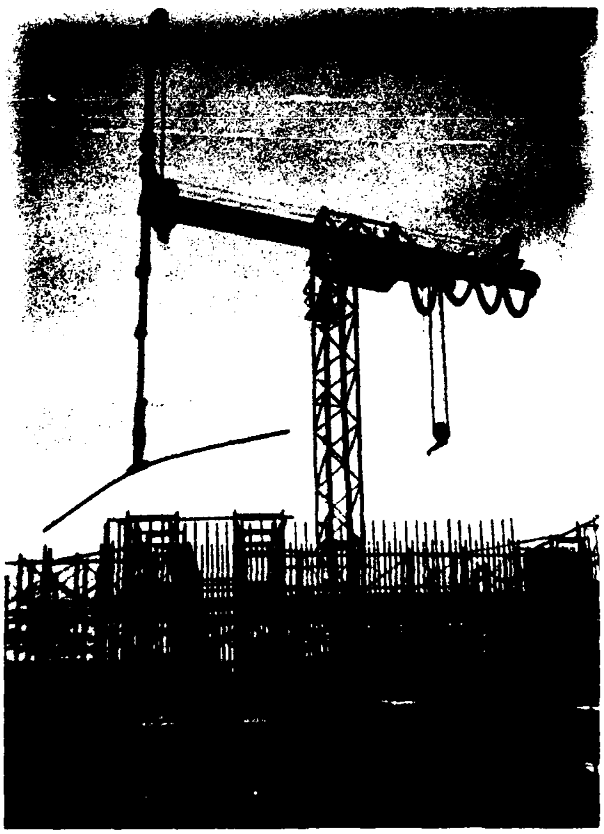

Figure 27. Takenaka robotic tower crane.

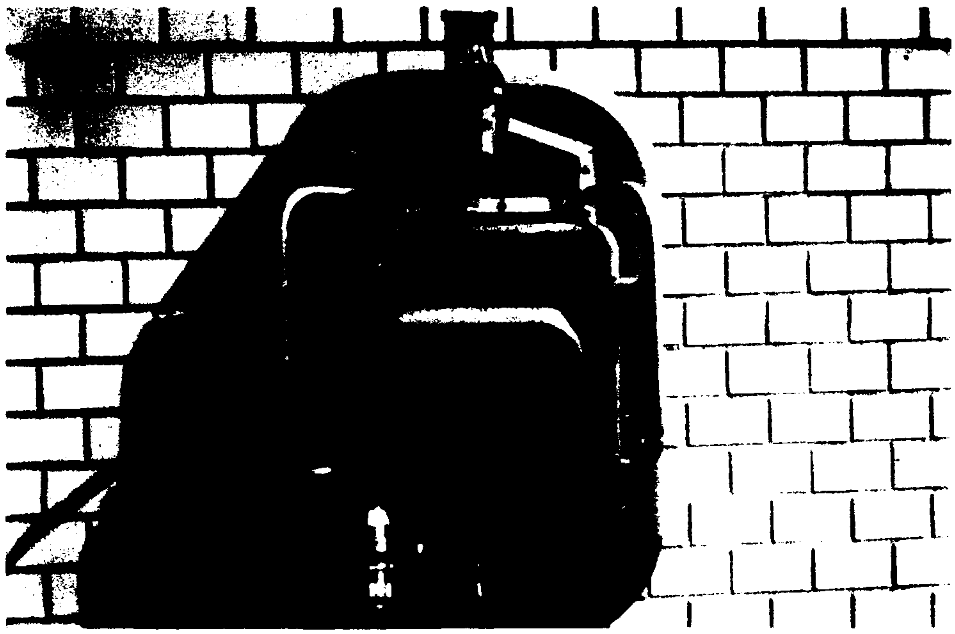

Figure 28. Takenaka tile-inspection robot.

manufacturers in Japan, only one, Misawa Company, will be discussed because it is representative of present technology.

Misawa company is a leading industrialized housing manufacturer. It prefabricates modules and components for on-site assembly. One of Misawa's main accomplishments is development of a material called PALC (precastable autoclaved lightweight concrete). Misawa spent over 10 years in research and development on this material. It has been heralded as a miracle breakthrough in housing, but is in fact similar to the foam concretes that have been used in Europe for quite some time. Its primary difference from European foam technologies is that it is autoclaved. This procedure enhances the qualities of the material, which are superior to nonautoclaved concrete in many of its properties. PALC has multiple uses: structural wall, fireproofing, insulating, soundproofing, waterproofing, and vapor retardant element. It is composed of approximately 20 percent solids and 80 percent air. It is a calcium, silicate, and water system that uses primarily powered silica, limestone, portland cement, and a special foaming agent.

In addition to materials technology, Misawa also uses automated production that features CAD/CAM systems for automated, integrated home design and fabrication. The modular system consist of the PALC panels and a steel framework. These modular cubes are combined into sectional systems that are transported to the site for assembly. Despite standardization, the CAD/CAM system has a capability for 900 variations of the floor plan. Module production incorporates the latest automotive manufacturing technology, including robotized operations. The industrialized manufacturers used experts from the automotive industry to train their production designers in order to ensure advanced technology in the design of production systems. Misawa housing manufacturing plants appear to be 7 to 10 years ahead of U.S. housing manufacturers.

The PALC plant has a capacity of approximately 30,000 homes per year. Misawa is exporting this technology; it has negotiated an agreement with Korea and is working on placing a plant in China. Attempts to begin a cooperative effort in the United States have not yet been successful.

4 ACADEMIC RESEARCH IN CONSTRUCTION AUTOMATION

As mentioned in the discussion about Shimizu, the latest concept in the development of robotized construction systems is the modularization of the robot functions. This work has been carried out at Waseda University and is known as the WASCOR project. The project is headed by Professor Yukio Hasegawa, one of the top robotics researchers in Japan. Professor Hasegawa was responsible for plant robotization at the Seiko watch manufacturing facility and has published many articles on robotization of construction operations. A 3-year study was completed in July 1985; it was composed of the following areas: industrialized building systems, re-bar placement, and concrete mold formwork.

As an approach to this study, the WASCOR group developed a modular robot specification system and categorized construction operations by work study analysis. The system divides operations into manipulative characteristics of individual robot components of hand, wrist, arm body, and locomotion. This specification is also being used in an attempt to modify construction processes so that they will be more compatible with manipulative characteristics as they presently exist. This work is a significant step in basic research by the combined efforts of some top Japanese researchers and 11 of the top construction firms. The success of a modular robot system at Shimizu is the first indication that the WASCOR concepts are valid and are being developed by the Japanese construction companies.

5 SUMMARY AND FORECAST

Japanese Lead in Construction Automation

The integrated approach to research and development in construction automation over the past several years has established the primacy of the Japanese in this technology. In Japan very large contractors perform much of the total construction, but in the United States construction is performed by many small contractors. Relative to the United States, there are fewer firms in Japan, but they are larger and thus have greater resources available. In addition, there is a closer liaison between the government and builders in Japan. Companies receive tax incentives for diverting profit towards research and development. Furthermore, a Japanese company that develops a new material or construction process can expect to benefit economically, in part, because of a climate of government regulation that is advantageous for advancing current technology. But in the United States contractors are dissuaded from using new technology because of the risk liability. Additionally, building codes in the U.S. restrict the use of any new construction technology, while in Japan codes allow its use. This practice benefits the technology leader.

As a result of these factors, the Japanese contractors have gained a substantial lead in automating construction processes. This is becoming evident internationally where the Japanese are gaining an increasing share of the market by virtue of their ability to do quality work at a lower price than their competitors.

Japanese Attitudes and Plans for the U. S. Market

Over the past decade, Japan has been working toward completing a plan of major projects including subways, railways, highways, and other public works. By 1985 this work was substantially completed, which resulted in a shift in the Japanese construction companies from the local market to the international market in order to maintain their project level. The Japanese are seeking new markets and naturally looking to the United States, as well as other countries, for new projects.

However, U.S. public opinion is against increasing the already large trade imbalance between Japan and the United States. Because the Japanese are very sensitive to public opinion in the United States, they have been careful in approaching the construction market here.

Two types of Japanese construction firms are presently developing U.S. markets: general contractors interested in commercial building and civil works and industrialized building systems manufacturers geared toward the residential housing market. The primary strategies for marketing Japanese construction technology are, first, the open bid system and, second, purchasing real estate for later development. In addition, there are occasional U.S.-Japan joint industrial ventures in which the contractor receives the award for construction.

The near term will see a significant increase in the amount of Japanese construction occurring in the United States in commercial and residential sectors for two reasons: the Japanese switch from domestic to foreign markets and the advanced state of Japanese construction technology. It may be helpful to note the precedents in both the automotive and electronics industries, where Japanese companies advanced the technology and then exported their products to the United States. Joint ventures similar to those now taking place in the automotive industry can be expected.

There is now an open effort by American companies to enlist the expertise of the Japanese industrialists, but this occurred only after the Japanese had proven in the marketplace that they were industry leaders. Something similar is developing in the industrialized housing sector in the United

States. Japanese firms desire to undertake joint ventures with U.S. firms, but because the Japanese have not yet proven themselves in the U.S. marketplace, U.S. firms are content to continue maintaining existing technologies. However, Japanese are preparing to move their technologies to the United States and have already begun making substantial purchases in real property. When it is economically feasible, housing manufacturing facilities will be built at suitable locations. In addition, it is likely that the U.S. industrialized housing manufacturers will go through a period of adjustment similar to that which occurred in the automotive manufacturing industry.

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