DEVELOPING AND MANAGING INNOVATIVE CONSTRUCTION TECHNOLOGIES IN JAPAN

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ABSTRACT: Construction technology innovation is becoming an increasingly important factor for the growth of many large Japanese firms. It has become essential that new construction technologies be identified, obtained on the most reasonable terms, and transferred smoothly to the construction site. This paper describes the four major factors that contribute to the development of innovative construction technology in Japan: (1) strategic alliances; (2) effective information gathering capability; (3) reputation through innovation; and (4) technology fusion. The paper also illustrates the technology evaluation process used by a typical large general contractor in Japan. It is concluded that global technology information gathering has increased the awareness of the large construction firms in Japan to outside technology. To implement synthesis of technology, these companies have participated in cross-industry research projects. The crucial link between innovation and business strategy in a large construction firm in Japan was found to be the long-range technology forecasting that integrates action of today with the vision of tomorrow.

INTRODUCTION

Many large construction companies in Japan regard innovative construction technology development as a key factor for success in today's competitive construction industry. By adapting corporate strategy to the opportunities created by new technology, many construction firms have turned technology into a winning competitive asset. The goals have been to adapt strategy to innovative technology, minimize technological surprise, form partnerships with organizations possessing complementary technology, capitalize on university research and emerging technologies, license strategic technologies, and accelerate growth through strategic technical alliances.

Therefore, many large construction firms in Japan have focused on building core competence by linking innovative construction technology with business strategy. The process of building this core competence consists in promoting the distinctive competence development needed for tomorrow's design and construction. Distinctive competence is defined as a set of activities that a firm organizes and coordinates more efficiently than other firms. It means differentiated expertise, complementary assets, and organizational routines that together allow a firm to coordinate a particular set of activities in a way that provides the basis for a competitive advantage in the design and construction market (Tucker and Scarlet 1986; Choi and Ibbs 1986).

There is a belief among Japanese construction firms that, in the near future, innovative construction technologies will be implemented on most construction sites and those companies that do not invest in such technologies will be left behind. The key issue of strategy is not how to break through technological barriers but how to put existing technology to the best possible use. The main connection between innovative technology and strategy has been through collaboration between organizations in the synthesis of technological capabilities and the development of core competence in a dynamic manner. The objective of this paper is to examine the broad issues and concepts involved in developing innovative construction technology in the context of large construction firms in Japan. An example project with its innovative technologies will be presented.

DEVELOPING INNOVATIVE TECHNOLOGIES

The term "technology innovation" encompasses three major activities: envisioning new work strategies, designing the process, and implementing change in all its complex technological, human, and organizational dimensions. It also refers to performing a work activity in a radically new way. Most large construction firms in Japan have a technology information center that continuously monitors various technology information. This information is used for strategic planning in construction technology development.

Although each construction company takes the initiative for its own innovative technology development, in the initial phases of growth, the Japanese government, through the Ministry of International Trade and Industry (MITI) and the Ministry of Construction (MOC), coordinates national technology projects and provides a variety of incentives, long-term directional visions of the future, and research and development (R&D) support (*Designing* 1992; Shimizu 1992). One such example is the WASeda COnstruction Robot research project (WASCOR), a national project for building automation that is directed by Professor Hasegawa at Waseda University (Hasegawa 1994).

In general, the major factors that contribute to the development of innovative construction technology in Japan comprise (1) strategic alliances; (2) effective information gathering capability; (3) reputation through innovation; and (4) technology fusion.

Strategic Alliances

The first major factor that contributes to the development of innovative construction technology in Japan is a firm's strategic alliances. Driven by increasing international competition at home, rising costs of technology development, the need to leverage scarce scientific and technical talent, and the desire to share the risks associated with the generation and commercialization of construction technology, large construction firms in Japan have begun to collaborate with high-technology and manufacturing firms in cooperative technology development. That is, research and development partnerships have become domestic and international phenomena. Various firms have used these strategic alliances to cope with rapid technological development in other industries, to adapt to the need to have new competencies built in a dynamic manner, and to withstand the intense competition resulting in the rapid introduction of

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new technologies. In addition, large construction firms in Japan have initiated alliances for the rapid generation, utilization, and diffusion of new technologies. The strategic alliances have been used in many areas and with diverse firms, leading to a synthesis of diverse capabilities.

Such partnerships have allowed Japanese construction firms to develop sophisticated knowledge of the full range of technical alternatives used in other industries. Closely monitoring relevant innovative technologies has broadened these firms' technical horizons and thus has opened new market areas for them. Joint-venture strategies for developing innovative construction technology in Japan have been technology driven; client driven (new customers, new market, or a new image); or risk driven (joint-venture strategies by sharing research and development risks).

It should be mentioned that competition on the basis of construction technology is not dependent on the in-house development of proprietary know-how alone. Instead, participation in research consortia, strategic alliances with firms, and partnering at the level of technology development are also increasing among Japanese construction firms. Firms are developing their technological posture on the basis of a mixture of technology, some developed in-house and some licensed or externally purchased. Although other industries have relied on the acquisition of small technology-based companies in order to supplement needed technology capabilities, this has not been a common practice among large Japanese construction firms. One reason is that these large companies have been rapidly able to learn and duplicate innovative technology through in-house development.

Another motive for Japanese construction firms to form alliances is simply to catch up. This situation occurs when the construction activity is a core component in the firm's portfolio but the firm is more of a follower than an innovator of construction technology. Therefore, forming a strategic alliance in this case strengthens the firm's competitive position. In this case the following questions must be addressed:

- What are the broad, readily apparent benefits of this strategic alliance for each partner?
- How can the two parties complement each other to create common strengths from which both can benefit?

Taken together, the answers to the previous questions should reveal an obvious win-win situation for both partners in developing new technologies. If such a situation does not exist, the chances for a successful alliance are low, as has been the case in past alliances, regardless of how fruitful the venture might appear.

Information Gathering

The second important factor for developing innovative construction technology in Japan is a firm's capability in gathering effective, valuable, and timely information. Among the large construction firms in Japan, it is customary for middle and senior managers from all areas of a company (i.e., design, construction, sales and marketing, technology, and other divisions) to collectively analyze the company's overall technological needs for the coming years. The purpose of this annual gathering is to collect a broad range of technological information from outside the company to review and evaluate new ideas. All employees are required to actively collect information. At every level, employees assume responsibility for keeping tabs on the marketplace and for bringing innovative ideas into the organization.

It is important to know that, when it comes to gathering information on technological innovations, the Japanese construction companies have not focused solely on the immediate competition. They collect information across the entire spectrum of competitors. However, keeping abreast of the ever-growing diversity of technologies demands sophisticated formal and informal intelligence-gathering capabilities. Formal capabilities might include a network of offices around the world to monitor patent applications or a system for finding innovative companies and technologists. Informal capabilities are based on a tacit understanding among employees, from senior managers to research assistants, that they have a responsibility to the company to gather and disseminate technical information, wherever it may reside.

Reputation through Innovation

The third factor that has contributed to further development of new construction technology in Japan is the reputation gained by developing innovative technology. A continuing technological leadership position typically results in a prominent reputation, which is a precious intangible asset that often appears to be at the root of commercial success. This does not imply an overestimation of the role of technology because, just like price and quality, technology on its own is barely an effective basis for innovative distinction. A notable reputation resulting from past technological success has beneficial effects on the company in the present and in the future with regard to both external (clients) and internal organizational affairs. One beneficial effect of such a reputation has been a greater ability to attract clients. Another significant factor is that technology becomes more vital for reinforcing a prestigious position through superiority in special attributes such as safety, durability, and resale value of a constructed facility.

Construction Technology Fusion

The fourth factor that has contributed to innovation in construction is the synthesis of technology; that is, diverse technologies from various disciplines are integrated to develop a new construction technique. Large construction firms in Japan continuously search for new ideas that have substantial potential for technology fusion.

CONSTRUCTION TECHNOLOGY EVALUATION

In addition to the previous four factors that create a business environment that contributes to the development of an innovative construction technology, it would also be necessary to develop an effective technology evaluation procedure to ensure the selection of innovative technologies that will have the highest positive impact on a firm's main line of business.

Japanese construction firms often involve many employees in decisions that are made by only one manager in the West. Such consensus decision-making processes have an institutionalized process, known as ringi, and an informal process, known as nemawashi. One example of how these processes are used in a project setting can be seen in the decision to initiate a new technology. Often, the decision to take on a large project involves the circulation of a proposal among middle managers. If a manager, upon reading the report, approves the proposal, he/she affixes his/her seal. When all relevant managers have approved the proposal, the document is then circulated among top managers, who have the consensus of middle managers on which to build. Smaller projects are sometimes taken on without top management input. In the process of getting ringi approval, a considerable amount of negotiation occurs on an informal level. Potential objections to the proposal are thus ironed out in advance. This informal process, or nemawashi, is considered essential to the ringi process.

Fig. 1 illustrates the process of a new technology proposal

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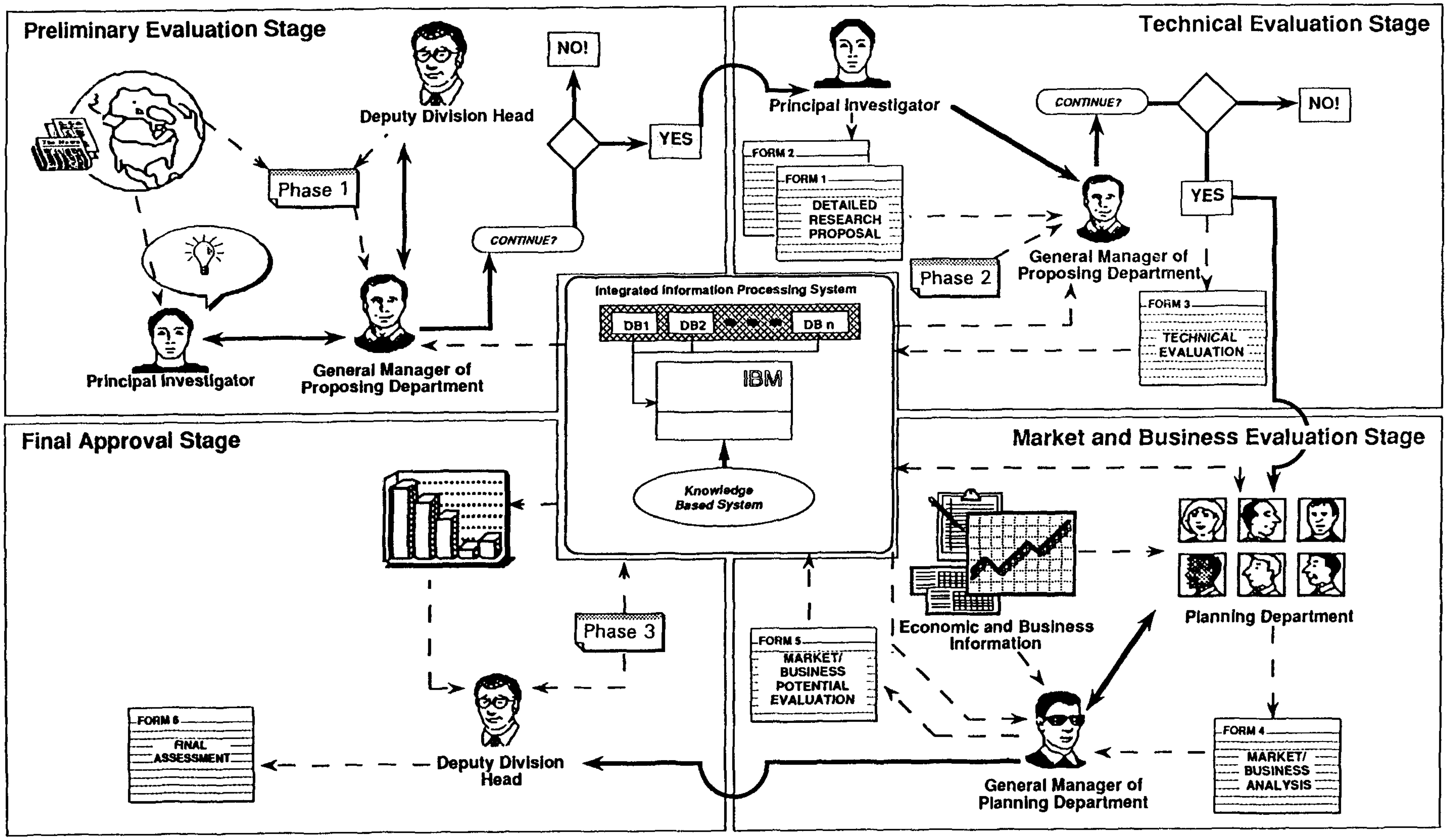

→ : **organizational flow**

- - - → : ***information/document flow***

FIG. 1. Organizational and Information Flow of Innovative Technology Proposal Evaluation

evaluation in a large Japanese construction firm. The technology evaluation process comprises preliminary evaluation, technical evaluation, market and business evaluation, and final approval. The policies for technology development in a Japanese construction firm should be viewed not in isolation but as a network of interacting policies that together serve to harmonize the goals of the company and its culture.

Phase 1, as illustrated in Fig. 1, considers the annual corporate strategies, such as enhancing technology-driven construction projects, the firm's relationship with clients, the level of automation and robotization of construction methods, and the design-construct interface. When an innovative technology development proposal satisfies the criteria of the initial phase, then phase 2 is used to answer the following questions:

- Do the group members have the required expertise?
- Do they have the necessary time to carry out the technology development?
- Do they exhibit the necessary motivation and interest in the development project?
- How technically achievable is the development project?
- Does the technology development project still satisfactorily complement the current technical corporate strategy?
- How does this new technology compare with the technology of the company's competitors?
- If competitors possess similar construction technology, how well does the proposed technology allow for technical differentiation?
- In light of what was learned in the feasibility study, is there any reason for discontinuing the new technology development?

If a technical proposal satisfies the criteria of the first two phases, then management will address the following questions in phase 3:

- How well does the new technology meet the firm's strategic technical goal?
- How well does the new technology fit in with such goals as new marketing in core business, strengthening of core business, licensing of technology, finding new areas for manufacturing, and enhancing the firm's image as a technology leader?
- How well does the new technology relate to current technologies?
- How innovative is the new technology?
- What is the current market size of existing or similar technology?
- What will the growth of the market be over the next five years?
- What are the group's abilities based on past performance?
- How clear is the proposed new technology development process?

It should be mentioned that the selection of a particular technology is very complex and ambiguous. Differential weighing of the factors is very difficult. Therefore, the most obvious approach to technology selection has been to select the innovative technologies most central to accomplishing the organization's strategy.

This complex process of technology evaluation by Japanese construction firms indicates how carefully a technology is selected in the context of a firm's technical corporate strategy. If a new technology successfully passes through these four phases, then a high probability exists that the technology might be practically applied on the construction sites, commercialized, and licensed to the other firms.

CASE STUDY

This section provides an example of smart building automation technology (SMART) in the context of the four previously described major factors that contribute to innovation: technology fusion, strategic alliances, effective information gathering capability, and reputation through innovation.

SMART's Technology Fusion

Innovation in construction technology by Japanese firms has rarely been achieved through the discovery of totally new technology by R&D departments; rather, it results from technology fusion. The former is a linear, step-by-step strategy of technology substitution. Technology fusion, on the other hand, is nonlinear, complementary, and cooperative. It blends incremental technical improvements from several previously separate fields of technology.

Therefore, mechatronics has provided a new method of integration for developing an innovative technology. The goals of mechatronics have been to utilize a multidisciplinary approach to technology development, to speed up transfer of technology, and to optimize the marriage between electronic and mechanical systems. The need for mechatronics is more obvious in the development of new construction technologies in which smart automated devices, information-based systems, and innovative construction methods have created the next generation of tools to be used on the construction sites of the future.

An example of such synergetic innovative technologies is the SMART system technology developed in Japan for automating the construction of high-rise buildings, and is described extensively in the *Engineering News Record* (''System'' 1993) and by Miyatake and Kangari (1993). The goal of this section is not to describe the SMART system but rather to demonstrate how technology fusion has resulted in an innovative construction technology.

This system consists of a set of new technologies that integrate high-rise construction processes, including the erection and welding of steel frames, the placement of precast concrete floor slabs and exterior and interior wall panels, and the installation of the various units. The system relies extensively on prefabricated components such as columns, beams, floorings, and walls. Assembly of these components is simplified by the use of specially designed joints, and a real-time computer control system is used for the assembly process.

This automated building construction system has combined mechanical and electronic technologies (mechatronics) to revolutionize the building construction operation. The idea behind this project was to add one technology to another and come up with a solution greater than the sum of its parts. One reason for selecting this project was that the ensuing technology would have the most dramatic impact on the firm's high-rise office building design and construction operation.

This innovative, robotized technology consists of five major components: (1) an automated transportation system; (2) innovative steel assembly; (3) a new automated welding system; (4) an advanced lift-up system; and (5) an integrated information-management system. A description of these systems follows.

The automated transportation system provides an innovative technique for material handling. The system, as shown in Fig. 2, is based on the just-in-time (JIT) concept, and operates 24 hours a day continuously. The system utilized advanced three-dimensional (3D) automatic positioning, which allows accurate transportation of construction materials. The material-tracking system supports graphic representation of material movement, provides early warnings of resource constraints,

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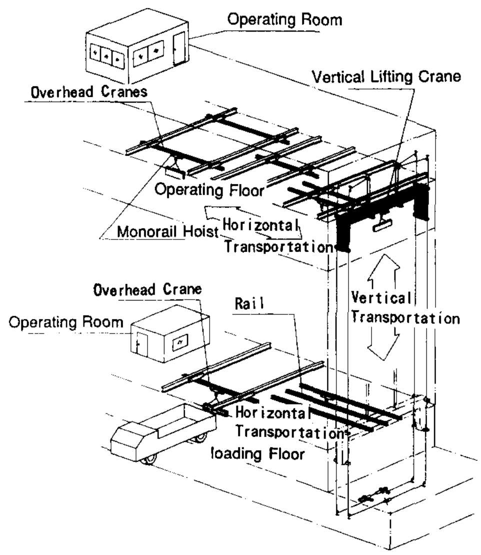

FIG. 2. JIT Material Handling and Assembly Systems

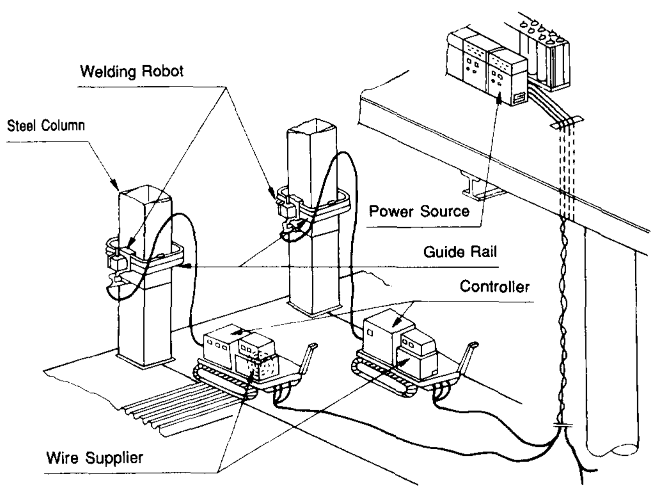

FIG. 3. System Outline of Welding Robot

and facilitates ease of use and understanding by nontechnical managers.

The second innovative aspect of this automated system, steel assembly, is illustrated in Fig. 2. Steel columns and beams are automatically transported to the designated locations, where they are mounted and assembled automatically with specially made joints. The innovative element of this system was the new shapes of the joints of the steel structure. Unlike those in the traditional procedures, the new steel structure connections are designed to realize a free-standing position upon insertion. To ensure accuracy of the steel frames during assembly, a new automated measuring system using laser beams was developed.

The third innovation, the new automated welding system, is shown in Fig. 3. Welding systems used in the manufacturing industry are usually designed for spot welding and are not directly applicable to the construction industry. Therefore, a new system for welding the construction elements was developed. The new system provides continuous horizontal multilayer welding and also utilizes laser sensors for detecting the welding groove. This has revolutionized the construction welding process by optimizing welding conditions through a database.

The fourth innovation is the advanced lift-up system, illustrated graphically in four steps. The sequence of activities as shown in Figs. 4–7 consists of climbing of upper and lower rings, securing the lower ring to the beam, climbing of jacking

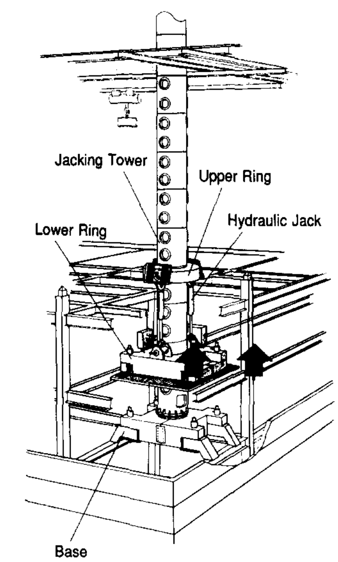

FIG. 4. Stage 1 of Lifting Mechanism: Climbing of Upper and Lower Rings

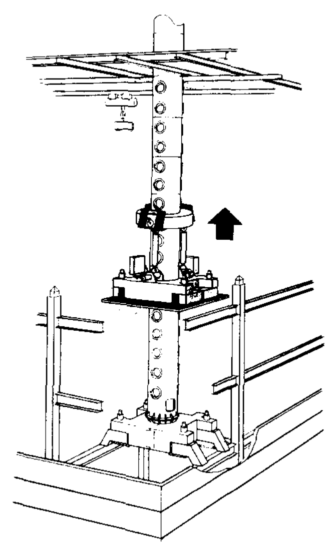

FIG. 5. Stage 2 of Lifting Mechanism: Securing Lower Ring to Beam and Lifting Upper Ring

tower and the base, and securing the base to the beam. This innovative system is the first to use the concept of four climbing jacks to construct a new floor. When one of the floors of the building is completed, the entire automated system is lifted vertically, and the work for the next floor commences immediately. Thus, construction work proceeds systematically, floor by floor, using the lift-up system. The system, which requires the synthesis of many existing technologies, is possible only with computer information integration.

The fifth innovative aspect of the system is its integrated information-management system. The system integrates information about material movement, which allows one to continuously track the status of materials, 3D computer-aided design working drawings and site layout, quality control, safety, machine management and lift-up system control, progress control (work schedule, and material order and delivery schedule), production and cost control, and resource allocation and management. The advanced monitoring and tracking system provides the project manager with immediate feedback on the status of the project throughout the construction process in order to avoid bottlenecks and other setbacks.

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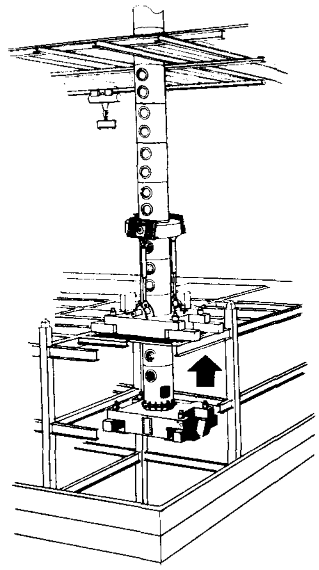

FIG. 6. Stage 3 of Lifting Mechanism: Climbing of Jacking Tower and Base

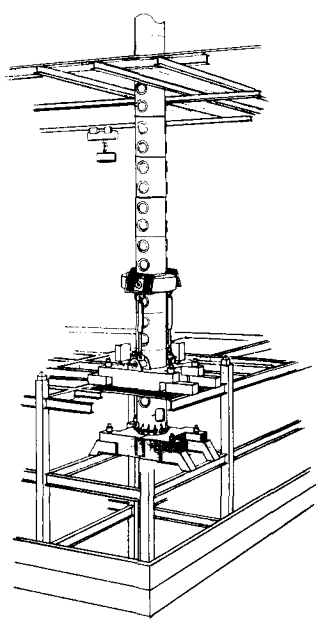

FIG. 7. Stage 4 of Lifting Mechanism: Securing Base to Beam

Strategic Alliances

In this case, a strategic alliance was formed between Shimizu Corporation and Mitsubishi Heavy Industries. These two companies have jointly developed the world's first automated intelligent system (SMART) for high-rise building construction. The system incorporates Mitsubishi's expertise in automated systems with that of Shimizu in building-construction operations. This competence fusion involved technology development, joint learning, joint engineering, and implementation. This strategic plan acts as a protective barrier against major technological surprises and is a device that facilitates the synthesis of technology. However, such innovative partnerships in construction technology development have represented a new organizational structure and have posed a unique management challenge.

In this case, the focus of innovative technology practices used by Mitsubishi Heavy Industries was to create and expedite new business opportunities as well as diversify into emerging areas in the construction industry, with the emphasis being on the latter. Mitsubishi Heavy Industries used a strategy that involved joint development and strategic alliances. In the case of Shimizu, however, the emphasis was on technology fusion.

Information Gathering

Cross-functional representation on project teams was essential to ensure that myriad perspectives were considered and that information from various sources was collected. Representation included teams of individuals from design, building construction, engineering, robotics manufacturing, and others. In the preliminary stage, a SMART prototype was developed to simulate and test the operation of the technology. A videotape showing the animation of the new automated construction process was used to provide information, to persuade the client to support the implementation of this innovative technology, and to convince the senior directors to further fund the development effort.

In this project, a series of meetings and workshops provided an effective means for collecting initial information and developing the original technology. Idea generation was particularly emphasized during the brainstorming sessions. In developing this technology, information from many sources was collected including information on intelligent manufacturing systems, new construction methods and prefabrications, reduction in the design-construction cycle, constructability improvement, new material handling systems, and JIT applications.

Company Reputation through Innovation

During the construction of the SMART system in Nagoya, 800 people, on average, visited the site every month—including owner's representatives, architects and engineers, R&D groups from various countries, local people, government representatives, and others. In fact, the project became a major attraction for visitors of the city of Nagoya. However, the main benefit of such a reputation has been a greater ability to attract clients through superiority in technology innovation, improved safety, and higher productivity.

LESSONS LEARNED

Technology improvement and innovation are the means by which may large Japanese construction firms have obtained greater value from their vast construction information. It is through systematic, opportunity-seeking behavior that leads to anticipated future benefits that Japanese construction firms have maintained their lofty position in technology development. The synthesis of automated construction technologies (along with simultaneous engineering) is at the root of new design and construction process development. A large number of innovative construction technologies have resulted from this unique Japanese approach, which integrates diverse technologies.

One major obstacle in recent years has been the high cost of developing new construction technology. Due to the current economic situation in Japan, many companies have initiated a new strategy by applying the technology to a small set of projects in order to gain experience with innovative technology initiatives, and then focusing resources on the most critical processes. Therefore, how essential that technology is to the execution of the firm's main line of construction has become a key factor in the development of innovative technology in Japan. Another new trend has been simulation modeling (Halpin and Woodhead 1976) of the innovative technology. It allows for the simulation of the design and construction process in increasingly realistic and complex settings. 3D graphics workstations are successfully used by Japanese firms to display

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material movement in relation to other components and to simulate effects of hostile environments, resource constraints, and rapid design and construction.

SUMMARY AND CONCLUSIONS

The present paper described the four major factors that contribute to the development of innovative construction technology in Japan: (1) strategic alliances; (2) effective information gathering capability; (3) reputation through innovation; and (4) technology fusion. Implementation of these concepts in an automated building technology was presented. The paper also illustrated the technology evaluation process used by a typical large Japanese construction firm.

Despite its promise to provide a competitive edge to companies that use it, innovative technology development is still a rare phenomenon in the construction world. A growing number of firms in the world are aware of its existence, but very few have undertaken serious initiatives to implement it. The reason for this is simple: construction technology innovation requires a large amount of capital and resources, so the conservative construction industry does not embrace it.

It is concluded that global technology information gathering has increased Japan's large construction firms' awareness to outside technology. To implement synthesis of technology, these companies have participated in cross-industry research projects. The crucial link between innovation and business strategy in a large construction firm in Japan was found to be the long-range technology forecasting that integrates action of today with the vision of tomorrow,

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