INTRODUCTION TO THE GENERAL TECHNOLOGY DEVELOPMENT PROJECT: RESEARCH AND DEVELOPMENT OF ADVANCED EXECUTION TECHNOLOGY BY REMOTE CONTROL ROBOT AND INFORMATION TECHNOLOGY

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Abstract:
Civil engineering construction work has always been accompanied by a high proportion of tasks that are either dangerous or unpleasant or both. Enhancing the general working environment and boosting safety levels are critical issues for the industry. Meanwhile, the industry has been slow to embrace IT, and there is substantial scope for the use of technology to boost efficiency, cut costs and improve quality levels in construction.

In a bid to address this issue, the Ministry of Land, Infrastructure and Transport launched a five-year project in FY2003 entitled Development of Construction Robots and Associated IT Systems. The aim of the project is to use cutting-edge telecommunications and robotics technology to minimize inefficiencies and eliminate the dangerous and unpleasant aspects of the construction process through the development of specific applications such as IT-equipped construction machinery and construction management systems using three-dimensional data.

This paper reports on the research and development work carried out by the authors in connection with the project.

Keywords: execution technology, information technology, robot technology, three-dimensional information, construction equipment

1. OVERVIEW OF PROJECT

Civil engineering construction in Japan today still involves dangerous and unpleasant work, particularly in areas such as rehabilitation of disaster regions, construction of tunnels and underground precincts, cliff area, and restoration of contaminated soil. Enhancing the general working environment and boosting safety levels are critical issues for the industry. Attempts to boost safety through R&D (research and development) into unmanned, remote-controlled systems are already underway. However, these tend to be both more costly and less efficient compared to traditional manned systems, and are generally limited to large-scale applications such as rehabilitation of disaster regions. Furthermore, the ongoing aging of the workforce in the construction industry will inevitably lead to shortages of young laborers and skilled workers.

It is hoped that the development of advanced construction aids and automated construction machinery systems using cutting-edge telecommunications and robotics technology will boost efficiency in areas such as rehabilitation of disaster regions, while also providing simple, low-cost solutions for ordinary construction sites.

The construction industry has been slower to embrace IT than other industries. Conventional construction sites, for instance, often still employ labor-intensive, paper-based two-dimensional measurements and data systems. A stronger emphasis on R&D is required in order to boost efficiency, cut costs and improve quality levels.

In a bid to address this issue, the Ministry of Land, Infrastructure and Transport launched a five-year project in FY2003 entitled Development of Construction Robots and Associated IT Systems. The project aims to develop IT-equipped construction machinery systems 3-D

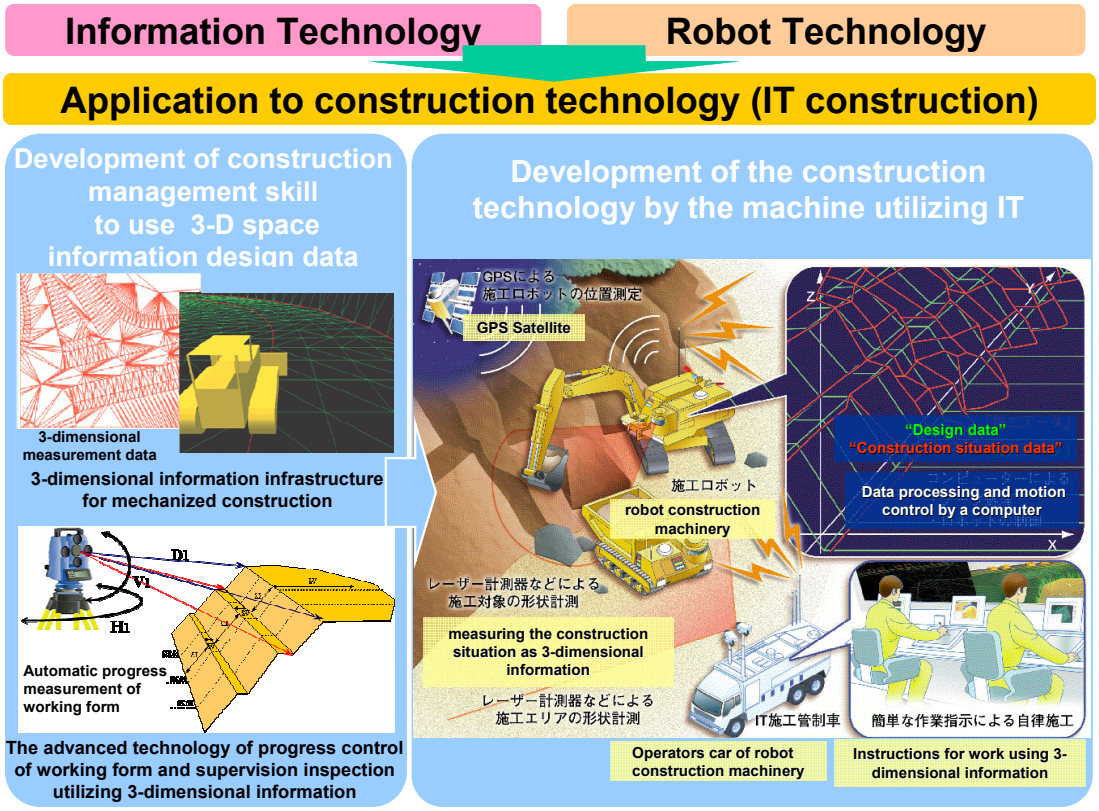

Fig. 1 Research and Development of Advanced Execution Technology by Remote Control Robot and Information Technology

construction information management technology as a means of eliminating dangerous and unpleasant aspects of the construction process and minimizing inefficient processes such as 3-D drawings and survey calculations, while at the same time equipping the industry to cope with the anticipated shortage of skill personnel.

1.1 Development of construction management skill to use 3-D space information design data

Robot construction machinery requires technology based on designs and 3-D structural shape data. To this end, a system for generating surface descriptions of 3-D design information was defined, along with a manual for application thereof. The system was tested in a field situation, with good results. The system will be further refined and modified, then promoted throughout the industry.

This research and development project was undertaken by the Research Center for Advanced Information Technology at the National Institute for Land and Infrastructure Management, a division of the Ministry of Land, Infrastructure and Transport. The project formally concluded in FY2005.

1.2 Development of the construction technology by the machine utilizing IT

One of the basic technologies underlying an IT-equipped construction system is the ability to render a screen display of three-dimensional topographical information, which is constantly changing due to changes in design information and site conditions, and convert simple on-screen instructions such as position information and task descriptions into machinery commands and instructions. This technology can be used to boost the efficiency of conventional construction machinery, and also in the development of construction robots such as automated excavators featuring IT and robotics technology.

This research and development project has been undertaken by the Advanced Technology Team at the Public Works Research Institute, and is due to finish in FY2007.

2. DEVELOPMENT OF CONSTRUCTION MANAGEMENT SKILL TO USE 3-D SPACE INFORMATION DESIGN DATA

One of the main objectives of a description method for 3-D design information is to enable the exchange and re-use of 3-D data at the construction stage. A data structure was proposed that would keep the volume of data relatively low and allow sufficient flexibility for modification. The data set was confined to shape information for roadways, including an imaginary centre line.

The data was subject to two conditions to enable usage in conjunction with construction robots:

1) Basic design information defining the design shape (flat plane/vertical profile alignment and horizontal section

shape) can be generated using the 3-D modeling features of design software.

2) Basic design data and topographical information (TIN) can be used to create and modify 3-D models.

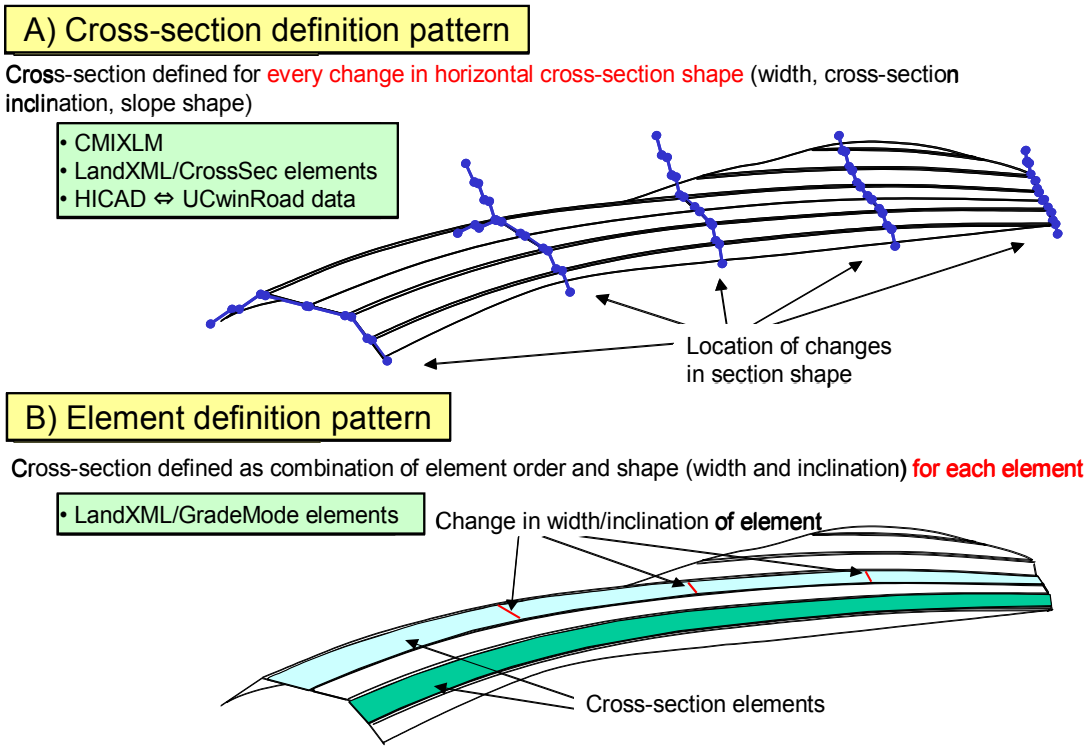

Fig. 2 Section definition: Pattern A versus Pattern B

2.1 Defining 3-D design shape

The 3-D design shape was defined as a combination of center alignment (flat plane/vertical profile) + horizontal section shape + topography, a data structure that provides sufficient for modification of design data. Applications use the 3-D design shape to calculate the required shape. Table 1 lists the types of information required in order to express the 3-D design shape.

Two definition approaches were developed, as shown in Figure 2. Pattern A defines the cross-section, which is updated for every change in width, cross-section inclination and slope shape (cuttings and embankments). Pattern B defines each surface element in terms of interval, width and inclination.

Pattern A was rejected in the research because it requires redefinition other than changing elements, thereby generating large data volumes. Also, Pattern B data can be readily converted to Pattern A data if required.

2.2 Structure of 3-D design shape data

Figure 3 shows the data structure for the 3-D design shape data.

The flat plane alignment and vertical alignment can be expressed as LandXML alignment elements. It was decided to use LandXML1.0 alignments without further modification, since these are already compatible with a number of applications. An improved version of GradeModel was defined as the data structure for the cross-section shape.

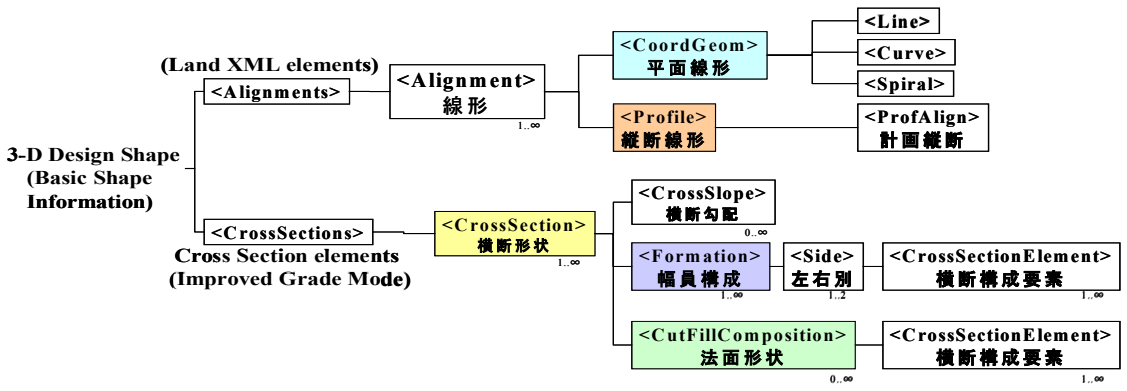

Fig.3 Data structure used to express the 3-D design shape

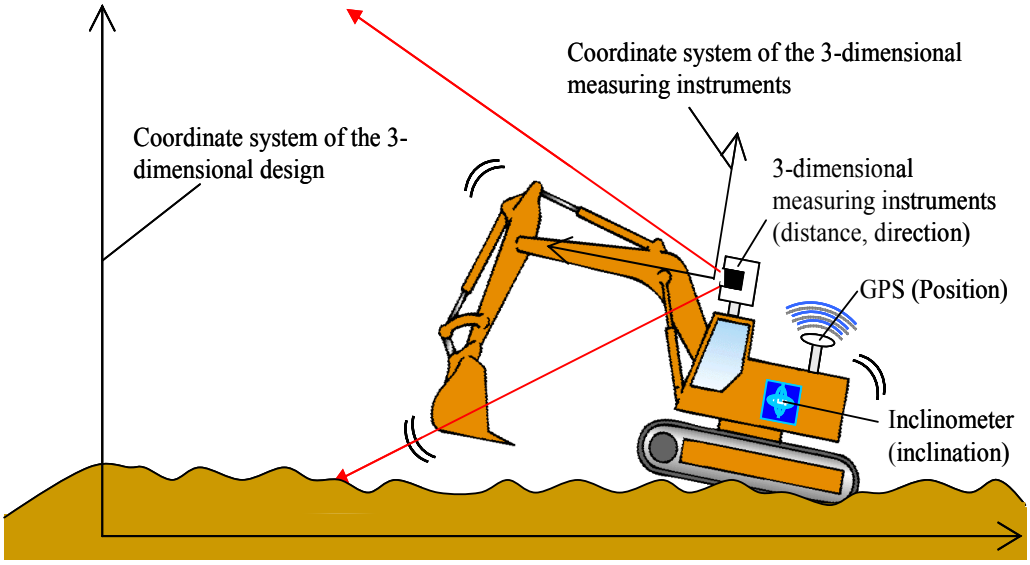

Fig. 4 The system which measures the construction situation as 3-D information

3. DEVELOPMENT OF THE CONSTRUCTION TECHNOLOGY BY THE MACHINE UTILIZING IT

3.1 Scope of study

The scope of the study was restricted to development of technology for describing work processes involved in excavation, loading and transportation of ground material by hydraulic excavators and crawler dump-trucks in highly dangerous situations or site conditions such as those encountered in rehabilitation of disaster regions and disaster prevention projects such as erosion control and sandbank reconstruction. It is envisaged that the technology will include hardware and software for robotic construction machinery, as well as project management systems such as process design and work schedules.

3.2 Overview of study

A prototype IT construction machinery system involving a combination of hydraulic excavators and crawler dump trucks will be trialed at a mock-up construction site during FY2007.

1) Stage 1 involves the preparation of 3-D information describing the target shape (i.e., the design) and the actual site conditions (i.e., topography) and machinery identification and position. This information is used by the remote-control or equivalent construction machinery operation system. This technology represents the fundamental basis for the development of the unmanned construction systems of the future.
2) Stage 2 involves the development of a prototype construction robot capable of translating simple instructions from the remote operator (such as task requirements, scope and location) into an autonomous work flow based on the 3-D information for work objectives (design) and site conditions (topography).

It is envisaged that the work flow will be only partly autonomous. The remote operator will be required to intervene in certain situations where the system is unable to continue functioning, for instance, if it encounters an unexpectedly large boulder. With respect to equipment such as the buckets and booms of the hydraulic excavator, the system should be capable of updating the work schedule autonomously on an ongoing scheduled line with changes in the working environment, to maintain a continuous excavation and loading as required.

3.3 Research program

1) Development of the system which measures the construction situation as 3-D information

Autonomous construction robots need to be able to process 3-D topographical information during the continuously changing construction process. Three-dimensional measuring devices (typically laser scanners) mounted on top of moving construction robots provide 3-D measurements that are then translated into coordinate positions.

2) Development of the display technology of the 3-D information for operation

(1)Technology to display 3-D information about the topography at the site and the design

It is necessary to display 3-D information about the measured conditions (i.e. topography) at the site overlaid with 3-D information about the target shape (i.e., the design). The screen should also be equipped to display simple instructions such as requirement and scope of task.

(2) Validation of prototype system

This involves the design and construction of a prototype system for providing the construction machinery operator (usually remote control) with 3-D

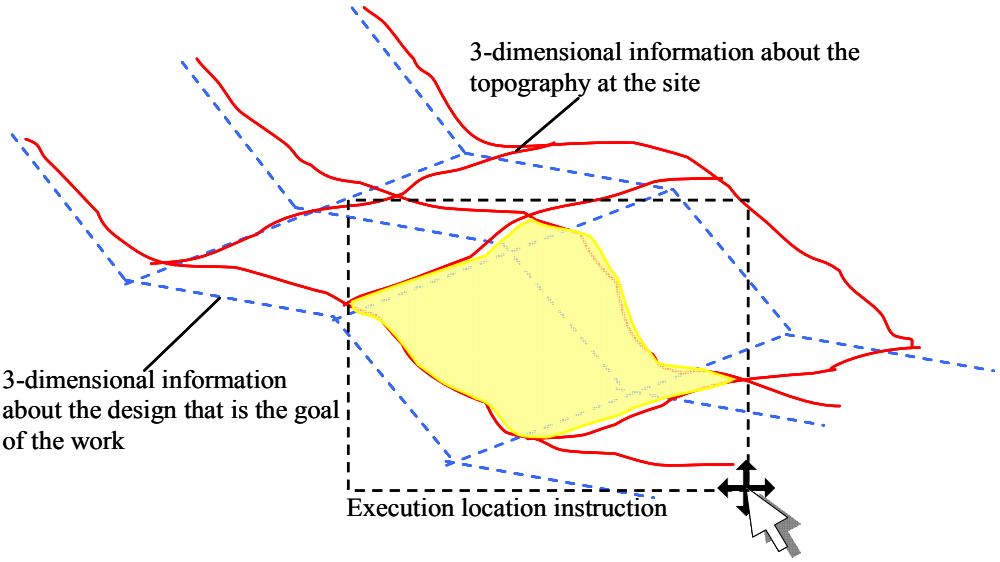

Fig.5 The display technology of the 3-D information for operation

information about the target shape (i.e., the design) and the actual site conditions (i.e., topography) as well as machinery identification and position. The functionality of the system will be evaluated through trials at a mock-up construction site.

3) Development of the automation technology (control technology of robot construction machinery) of construction operation

(1) Analyzing the movement of construction machinery under the operation of skilled operators

A numerical analysis reveals differences in the loci of movement of construction machinery under autonomous control and machinery operated by skilled operators. To this end, the movement and lever operation of construction machinery and equipment is measured during operation by multiple skilled operators.

(2) Development of automatic control technology for construction machinery

Control algorithms to enable automatic creation of construction robot equipment operation programs are developed using 3-D information about target shape (design) and actual conditions (topography), with reference to the operator data described above. These are accompanied by technology for measuring and controlling machinery position and orientation in real time.

(3) Validation of prototype system

The technology studied in this project will be used to design and build a prototype IT system for construction machinery involved in major earthworks — specifically, the excavation, loading and transportation of ground material by hydraulic excavators and crawler dump-trucks. The functionality of the prototype system will be validated through trials conducted at a mock-up construction site.

4. CONCLUSIONS

Construction robots have been under development for some 20 years now. The development process has concentrated on resolving specific issues and refining the remote-control and unmanned systems, with the focus on developing more advanced, accurate and low-cost technologies for measurement, data manipulation, transmission and control.

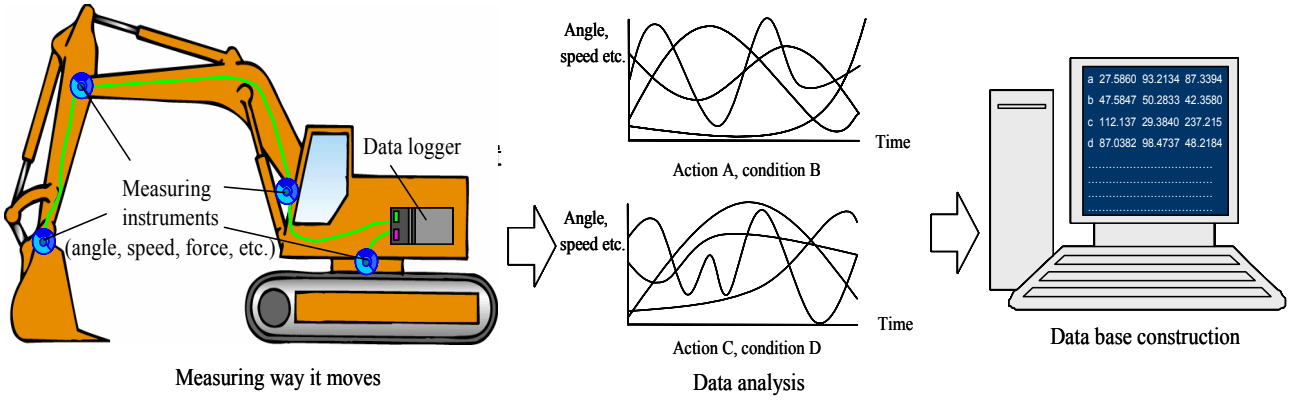

Fig.6 Analyzing the movement of construction machinery operated by skilled operators

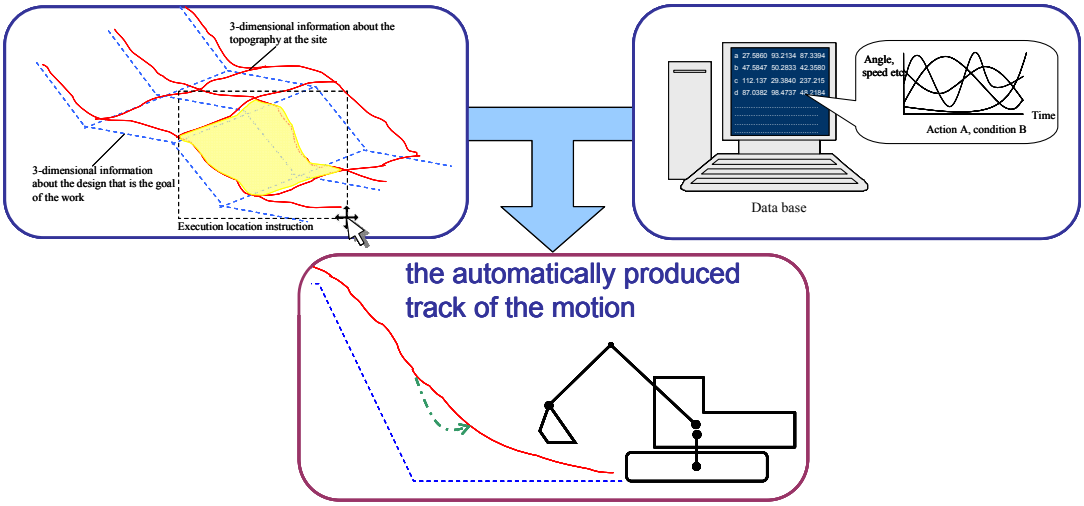

Fig.7 Automatic construction machinery control

This project seeks to develop fundamental IT and RT technology for a typical construction machine, the hydraulic excavator, with a view to introducing the technology as widely as possible.

It seems not unreasonable to expect that the same production control technology that has been embraced so extensively in the production sector could also be successfully introduced to civil engineering applications, particularly in the case of NC (Numerical Control) machinery and mass production design and production systems. Furthermore, given the inherently dangerous nature of construction work, it makes sense to try to minimize the number of workers on site. In order to address these fundamental issues, we need to be able to make appropriate use of spatial information, particularly on outdoor sites. The lack of progress in this area to date can be attributed to the absence of the necessary element technologies.

The element technologies can be generated through further development of product model descriptions for the design and construction shape, a Context Awareness system that combines position information with observations of the surrounding environment, and systems for management and reuse of construction outcomes.

The aim is to eliminate manual processes such as stake installations and ongoing measurements, thereby reducing the number of assistants required. The “Construction Navigator,” a system that provides operators with work instructions and reference information and sends design drawings and measurement data to construction machines, could be located remotely or even in a vehicle. The aim is to enable a single worker to operate two machines, through automated construction processes. It is hoped that the technological specifications and combined construction model for the programmable backhoe can be freely modified and improved within the consortium.

Other strategic issues include safety, efficiency and reliability in rehabilitation of disaster regions, the need for skilled construction technicians to improve quality assurance levels, and risk management associated with the use of unskilled workers. Of particular concern is the rate of work-related injuries and deaths relative to the number of workers in the construction industry, which is nearly four times higher than the average for all other industries combined. The rate of accidents directly associated with construction machinery alone is close to the average for all other industries, increasing in proportion to the level of investment. Although these figures can be interpreted in a number of different ways, it is clear that information technology has a part to play in improving the situation.

In closing, the authors would like to thank all those involved in the project and note that they look forward to new developments such as production engineering in the construction industry and construction robots.

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