VALUE CREATION BY AUTOMATION AND ROBOTICS IN CONSTRUCTION: AN INTRODUCTION

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Abstract: In the decades to come, building production will concentrate in the metropolitan centres of the world due to the migration of the world's population to the major cities.
An improvement of the construction process in densely populated inner cities will be the task of the future. This focuses on performance management, construction engineering and construction management. New developments being discussed in this field are new design strategies, human machine technologies, employee safety, progress monitoring, distributed production information and Personal Digital Assistants (PDAs).

Keywords: value creation, performance management, construction engineering, construction management, automation, metropolis

1 INTRODUCTION

1.1 The building industry tomorrow

Changes in building production are essential if the world of construction is to improve. The changes are also necessary because the next few decades will see an enormous migration into the cities. The forecast is that in 2015, 55% of the world's population will live in the urban areas (see Figure 1). These metropolises (densely populated inner cities with their agglomeration) impose their own requirements on construction management and production systems.

Figure 1: Quota of urban population [9]

Quota of urban population

	1995	2015
Global and total	45%	55%
Developing countries	39%	50%
Industrial countries	75%	80%

→ Urbanisation

The following developments occur in the Western European construction industry. In Germany, building production has fallen by 35% in five years; in the Netherlands, by 15% in three years. In other countries on the European continent, the construction industry is hesitant. In Britain, the innovation process 'Rethinking Construction' was the prelude to a change in the system. The development of the 'chip' and the 'chip industry' has completely changed society as a whole. The developments in construction in recent decades can also be attributed to these changes.

1.2. Changes in construction

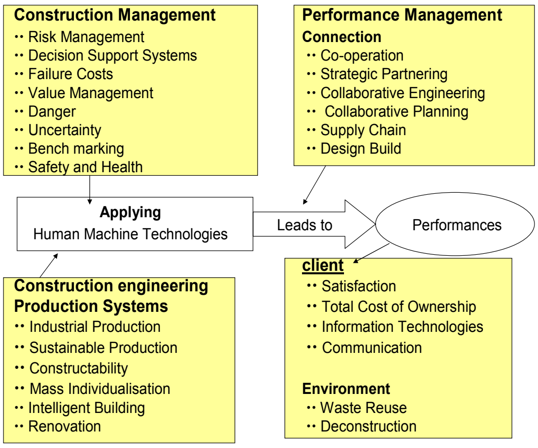
The developments of the construction process are the result of a set of changing circumstances and conditions. These changes encourage developments of technologies to ensure the creation of a process that leads to improved performance for the client. These developments are based on an analysis of the Status Report issued by the CIB Commission TG27 (2001) [1] and of the proceedings of the ISARC 2003 Symposium: The Future Site [2].

In this analysis automation in construction is addressed from the perspective of the performance of building projects serving the client and the environment.

- How can a connection between performance requirements and building production be established and improved through the use of Automation in production?
- How can automation in construction engineering change the role of being a responsible partner in a changing world?
- How can construction management systems contribute to the improvement of production by Automation?

When all building production is ultimately designed to lead to improved performance and a satisfied client, it is always difficult to keep sight of the overall picture and this final goal. Components develop and result in the required performance improvements. The overview in Figure 2 shows the relationship between the various aspects of automation in construction. Construction management, construction engineering and performance management help the managers meet the needs of the client.

Figure 2: Relationship between management, engineering and performance.



1.3.Examples of developments by automation

This paper looks at all three of the following aspects:

1. Performance management with a contribution about the development of new design ideas to meet client requirements in a different way.
2. Construction engineering with a contribution about the improvement of Human Machine Technologies,
and about worker safety on the building site.
3. Construction management with contributions about monitoring project progress,
about collection of the design and management information,
and about support of the work floor manager with PDAs.

We will elaborate on these examples in paragraph 2.

2. DEVELOPMENTS IN AUTOMATION IN CONSTRUCTION

2.1 Automation in performance management. The development of a new design strategy

1. The challenge when building in metropolitan inner cities is the development of production systems that go further than the Automation or robotizing of traditional activities on the building site which are normally carried out on site by construction workers.
A special form of Automation and Robotics is prefabrication. Prefabrication moves work away from the building site to a factory. For construction workers, this is an enormous improvement because working conditions are checked and managed far more effectively. Production is moved to a certain extent but does not really change. However, production only really changes when new processes are developed. Functions are no longer assigned to the traditional building elements and are no longer carried out with those materials that people are used to.

2. Richard's contribution [3] draws an analogy with the development of the printed circuit board. Under the term 'reproduction', he describes an approach that leads to the redesign or re-engineering of the construction process.
"Reproduction implies innovative processes capable of short-cutting the long sequential operations of craftmanship nature - i.e. capable of categorically simplifying the production, as notably illustrated by the analogy of Printing / the Printed-Circuit / the Printed Plumbing Core. Using performance criteria, in order to avoid a captive image from the past, one can identify promising options through the "Technology Matrix" (where processes interact with materials) and thereafter generate building system aiming at Reproduction."
"Reproduction = priority to ideas rather than machinery."
"Reproduction is the introduction of an innovative **technology capable of simplifying the production** of complex goods, of short-cutting long sequential operations. Therefore achieving more substantial economies than mechanizing, automation or robotizing around the traditional construction methods."
"Instead of investing straight into machinery, Reproduction is basically calling upon Research & Development for "ideas" to generate a simplified process. Of course, Reproduction is not necessarily available as a downright option: it is often present together with some of the other degrees industrialization."

3. Richard's contribution gives a whole new dimension to Figure 2. Richard invites us to come up with new ideas. Not for improved production systems with or without the use of automation or robotisation, but new ideas focusing on the performances that ultimately have to be achieved! All these new ideas will have to be generated by a combination of new designs, new forms and new materials that meet the requirements for building in a metropolis. This will create new production systems for the Future Site.

Construction engineering for metropolises (Figure 2) can undergo an enormous impulse. Automation creates the preconditions for following new avenues which will bring us closer to the performance requirements of both client and metropolis. The opposite also applies: without automation, these new ideas cannot be developed into new processes.

2.2. Automation in construction engineering

2.2.1. The importance of Human Machine Technologies

1. The safety regulations for building site work impose more and more restrictions on the loads workers are allowed to carry, prepare and apply using only the resources of their own body. But building contracts will expect an increasing amount of effort. Take high-rise construction in metropolises and the attachment of wall cladding to these buildings, for example. Fitting heavy window panes or attaching wall panels with great precision is a challenge for the robotics industry to come up with new tools for this purpose.

2. The article by Choi (et al.) [7] presents a construction robot that is a hybrid type robot using pneumatic actuator and servo motor. "The hybrid type robot can be used in glass mounting on panel fixing. The hybrid type robot mechanism has a wide range of workspace and precision, and consists of a serial and parallel part. The pneumatic actuator has been widely used in industry site because of its low-cost, compact high rate of power/weight and reliability. The restricting factors preventing the use of pneumatic actuators for accurate control arise from highly non-linear dynamic properties such as air compressibility and friction effects, which combine to severely decrease time responsibility and positioning accuracy. The sliding mode controller is adequate to such as cylinder that is strong non-linear property. The developed construction robot with pneumatic actuator using the sliding mode controller used in the work of an attaching the ceramic tile."

3. With this article, Choi (et al.) make a significant contribution to the development of human machine technologies (see Figure 2) to help in heavy physical work in high-rise construction.
In spite of all the modern production systems, much of the work will continue to be carried out on site. With regard to health, work speed and quality, mechanisation of the work on site will remain an important goal for the successful development of major building assignments in our metropolises.

2.2.2. Worker safety on the building site

1. Complex high-rise construction work in a metropolis is an extremely risky undertaking. Complex logistics on the building site and in full inner cities require construction times to be kept to a minimum. This leads to highly compact building processes and production systems that are sometimes unsafe and create many minor and major risks for the construction workers.

2. "The work described in the article of Abderrahim (et al.) [5] deals with the development of a particular security system, using both existing commercial technology and specially designed equipment. The compulsory safety helmet required for all workers in construction sites is used as the base to accommodate miniature positioning and communication instruments. The position and ID of each worker is sampled periodically and sent via radio to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. According to this, workers and machines' positions are known in each instant and risk situations may be recognised immediately and therefore damage can be prevented. If certain workers and particular machinery and equipment elements are not supposed to be in certain locations for safety reasons, an automated system can be used to detect the situation and make the adequate decision to prevent a possible accident. The proposed system is meant for modern construction systems where workers and automated/semi-automated machines coexist."

3. If we apply the article by Abderrahim (et al.) to Figure 2, we see that it can make an important contribution to the minimisation of risks. The instrument is designed to localise and detect the risks on site that cannot be prevented and to inform construction workers with warning signals of approaching danger (e.g. machines or crane loads) and to prevent people falling into openings in floors.
By using databases, radio signalling and normal radio communication equipment, automation (ICT) can reduce the remaining risks on the building site which cannot be prevented by collaborative engineering of by improving production systems. This makes it an important instrument in the final phase of risk management. The automated system adds value to the development of high-rise building in metropolises by perfecting risk management.

2.3. Automation in Construction Management

2.3.1. Monitoring project progress

1. The complexity of building in a metropolis prompts the inclusion of performance indicators other than the traditional ones in a contract. A traditional contract gives the contractor the responsibility to supply products and to assemble them into a structure, and he is given a certain

amount of time and money to do so. He is also expected to use the necessary capacity in terms of workers and machinery. In the traditional system, the contractor provides a design with drawings and calculations.
The new construction assignment challenges the construction industry to carry out projects under new contract conditions. The newness of these contracts becomes apparent from performance indicators other than the traditional ones. The traditional performance indicators were primarily time, money and a detailed design with materials to be supplied. The new types of contract place responsibility more integrally on the contracting parties.
This supplements the traditional performance indicators with new ones and creates the need for integral monitoring and checks of the project progress.

2. Navon's article [4] describes the options and developments using examples.
"There are also briefly described together with the concept of measuring indirect parameters and converting them into the sought indicators. These are: (1) labor and earthmoving productivity, based on measuring the location of workers, or earthmoving equipment, at regular time intervals. (2) Progres, based on the above data, or data collected from a tower crane. (3) A comprehensive control of construction materials, starting by monitoring orders and purchasing up to the movement of the materials on site. (4) Monitoring the status of guard rails in order to prevent falls from heights."

3. If we apply Navon's contribution to Figure 2, we see that developments in the world of ICT have a positive impact on the development of the possibilities of all kinds of aspects of construction management. They are the tools the contract partners can use to monitor the progress of complex contracts. The automated monitoring system adds value to the development of new types of contracts.

2.3.2. Acquiring design and management information

1. Effective, tight management of projects during the development, design, execution and maintenance phases depends on a great deal of information. Without the right information, management is more like gambling and guessing than informed control. Construction in metropolises entails working with more partners than people are used to. These partners not only work together on the same project, they also need one another because they have their own projects which depend on one another. For example: flats above shops, offices with shops above a railway station. Various owners all have their own interest, backgrounds, needs, requirements, functional specifications, decision-making processes, etc. These aspects each generate their own specific information, so the manager who has to head up integrated projects in a metropolis is confronted by an immense flow of information. This information is not fixed, so the manager also has to rely on the quality of the information he is working with.

2. The article by Van Leeuwen (et al.) [8] discusses this problem and works out a proposal for not distributing this information but for sharing the various information sources.
"The validity of information that a manager obtains from partners in a project can only be guaranteed by sharing of the information resources. This means that, rather than providing a copy of the information, the information is accessed at its source where the provider of the information has full control (and responsibility) over it."
"To achieve such sharing of information, Van Leeuwen (et al.). propose a change of the paradigm 'distributed product information' from the supplier point of view to the consumer point of view. 'Distributed' no longer means 'sent to many clients' but rather 'accessed at many providers.' Sharing distributed information resources has the potential to improve business processes in many ways:

- Avoiding unsolicited communication, the traffic of information is reduced, even if there is an increased amount of wanted traffic;
- It improves the validity of information, because it remains under control of the provider;
- It increases the quality of information, since it can answer a specific request or even result from a, possibly automated, dialogue;
- It helps to integrate business processes by keeping the relationships between the processes and their output data active."

3. In the article, Van Leeuwen (et al.) provide an important insight into the development that ICT can stimulate possibilities for the exercise of construction management (see Figure 2). With the right ICT tools, the manager (the client) has up-to-date information about all production systems, all risks and uncertainties, and all design decisions and design options. This information enables him to follow how plans and production are developing on a daily basis (without lacking information) and how they ultimately meet the requirements of the client. It would probably be impossible to complete these complex construction projects in our metropolises without these kinds of ICT systems.

2.3.3. Support of the work floor manager with PDAs

1. These days, the on-site construction manager has serious problems having building production information processed efficiently, quickly and on time. On complex high-rise or underground construction projects in the metropolises, production information is not only processed to monitor progress

and quality. A lot of data about the vicinity (groundwater level, stability of adjacent buildings, good traffic circulation) has to be processed every day. This is not only required to monitor progress, but also to prevent damage and ambient danger and to minimise risk.

2. The article by Kimoto (et al.)[6]:
"This paper reports a development of mobile computing system with PDA (Personal Digital As sistants) for construction managers on construction sites. First, this paper describes the aim, the concept based on End User Computing, and the essential element of the mobile system. This also shows the necessary functions for the mobile computing, and the concept of this computer-aided engineering system. Secondly, this paper describes the structure of the system and the outline of subsystems: Progress Monitoring System, Inspection System, Checklist and Reference System, and Position Check System".

3. To convert the work of the on-site construction manager into a substantive role and less that of an administrator of important information, it is essential to develop mobile computing systems in accordance with the proposal put forward by Kimoto (et al.).
The reporting process is fully automated from the location in the project where the information is checked or available. Using a mobile computing system in combination with the distributed product information set out by Van Leeuwen (et al.) (see elsewhere in this volume) would cut out a whole series of administrative activities throughout the project and increase the efficiency of data management. All data on the various construction management aspects in Figure 2 are collected integrally and processed in real time.
When this data is linked to pictures from a digital camera and speech recognition in the future, it will be a real help to the construction manager, who will then have more time and attention for the actual content of the project.

3. CONCLUSION

The building assignment will focus on metropolises, which sets specific requirements for performance management, construction management and construction engineering.
Clients need individual treatment and a specific approach designed to solve their problem and meet their demands. They are less concerned in the size of the investment, but are becoming more and more interested in the total cost of ownership and life cycle cost. Nowadays, clients are less concerned with the structure itself. They pay more attention to its functional use, and this primarily stimulated by the use of information and communication technology in the projects.
Design strategies improve performance management.

Construction engineering is changed by the application of more industrial production, sustainable production, mass individualisation, and intelligent building to improve constructability.
Construction management has to deal with safety and health, uncertainty and danger. Developments are taking place in risk management, value management and decision support systems supported by partnering collaborative design, supply chain management.

Better ICT tools provide the manager with better information faster by using distributed systems and PDAs.

These developments demonstrate that there is plenty of room for improvement in all process elements of construction projects in metropolises.

This underscores the economic importance of automation in construction. The ultimate goal is the value creation construction is capable of.

REFERENCES

[1] Van Gassel F, Maas G., *International Status Report on Aspects of FutureSites*, CIB TG27 "Human-Machine Technologies for Construction Sites." CIB 265. ISBN 90-6814-119-8. CD-ROM

[2] Maas G., Van Gassel F. (editor), 2003, *Proceedings The Future Site ISARC2003*, Bouwstenen 75, 675p, TU/e.

[3] Richard R.-B., 'Industrialised Building Systems: Reproduction before Automation and Robotics', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p.333-338

[4] Navon R., 'Automated Project Performance Control (APPC) of Construction Projects', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p. 79-82.

[5] Abderrahim M., Garcia E., Diez R. and Balaguer C., 'A Mechatronics Security System for the Construction Site', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p. 155-160.

[6] Kimoto K., Endo K., Iwashita S. and Fujiwara M., 'The application of PDA as Mobile Computing System on Construction Management', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p 479-485.

[7] Choi H.-S., Han C.-S, Lee K.-Y. and Lee S.-H., 'Development of Hybrid Robot for Construction

Works with Pneumatic Actuator', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p191-196.

[8] Van Leeuwen J. and Van der Zee A., 'A distributed Object Model of CSCW in the Construction Industry', *Proceedings The Future Site ISARC2003*, Bouwstenen 75, TU/e, p221-228

[9] Both (K.) and Haack (A.), Present-day design fire scenarios and comparison with test results and real fires: Structures & Equipment, Presentation: 1st International Symposium "Safe and Reliable Tunnels" Prague, 4-6 February 2004