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Mechanising, Robotising and Automating Construction Processes

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1. Introduction

Building objects are produced by people who perform the necessary tasks using equipment. On the basis of preconditions, the process designer can have a particular task performed by a specific combination of a worker and equipment. The worker performs a number of tasks and the equipment does the rest.

Nowadays, newer, more suitable technologies are becoming available. In order to use these technologies successfully, it is essential to have a good understanding of the work processes of an object that is to be built.

The terms mechanising, robotising and automating are defined in order to be able to describe the physical, cognitive and organising tasks in relation to the possible use of human-machine technologies. It sometimes makes more sense to redesign the building products to achieve a more effective and efficient building process using workers and additional tools or machines.

Mechanising, robotising and automating construction processes is necessary in order to reduce production times and costs, improve working conditions, avoid dangerous work, allow work to be performed that people cannot do and increase performance. For the construction industry, more and more human-machine technologies are becoming available, but their use does not automatically lead to more effective and efficient construction processes.

Building expertise is the domain of the professional builder and not of the process engineers who look to apply the technologies in the construction industry. The implicit know-how of the builders and construction process designers regarding the execution of construction processes has to be made explicit. The builder's implicit know-how comprises knowing how to choose the sequence of the building elements, how to join the elements, where the elements fit in the construction as a whole and how they have to be positioned.

This chapter contains a systematic definition of the terms mechanising, robotising and automating and explains an analysis method with which a worker-equipment system that produces better performance can be designed.

2. An automated construction system

In Japan, construction process designers have upscaled the worker-equipment system into a cohesive building production system to find solutions to problems such as the aging of

workers, a higher training level for employees and the low numbers of young people looking for jobs in construction (Obayashi, 1999). A building production system can be defined as a technical installation that assembles construction elements into a building. In this context, an installation can be seen as a collection of people, tools and machines, computers and telecommunications equipment that may all be working together. If we couple this definition to the various tasks required for the performance of a building activity – physical, cognitive and organising tasks – we see production systems subdivided into traditional, mechanised, robotised and automated building production systems. Table 1 shows the relationships between the different parameters using human-machine technologies.

Construction system type	Physical tasks	Cognitive tasks	Organising tasks
Traditional	Workers Equipment	Workers	Workers
Mechanised	Equipment	Workers	Workers
Robotised	Equipment	Computers and software. Means of communication.	Workers
Automated	Equipment	Computers and software. Means of communication.	Computers and software. Means of communication.

Table 1. Types of construction systems in relation to various tasks (Van Gassel, 2003).

An automated construction system consists of an assembly area where building work can be carried out regardless of the weather, an automatic hoisting system for the assembly area, an automatic vertical and horizontal conveyor system and a centralised information system to execute and manage organisation tasks (see Fig. 1).

Fig. 1. An automated construction system in Japan.

3. Developments in construction processes

Developments in construction processes are the result of a set of changing circumstances and conditions, such as enormous migration into the cities. The forecast is that in 2015, 55% of the world's population will live in urban areas. These metropolises impose their own

requirements on construction management and production systems. These changes encourage the development 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 in 2001 by the CIB Task Group TG27 'Human-Machine Technologies for Construction Sites' (Maas & Van Gassel, 2001) and of the proceedings of the ISARC2003 Symposium: The Future Site (Maas & Van Gassel, 2003).

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. The overview in Fig. 2 shows the relationship between the various aspects of automation in construction: construction management, construction engineering and performance management help the process designers to meet the needs of the client and society.

Construction Management
- Risk management
- Failure costs
- Value management
- Danger work and processes
- Uncertainty
- Benchmarking
- Safety and health

Construction Engineering
- Industrial production
- Sustainable construction
- Constructability
- Mass customisation
- Modular construction
- Renovation

Performance Management
- Co-oporation and partnering
- Strategic planning
- Collaborative design and engineering
- Supply chain management
- Design and build
- Lean construction management

Applying Human Machine Technologies

Performances for client and society
- Satisfaction
- Total cost of ownership
- Available information
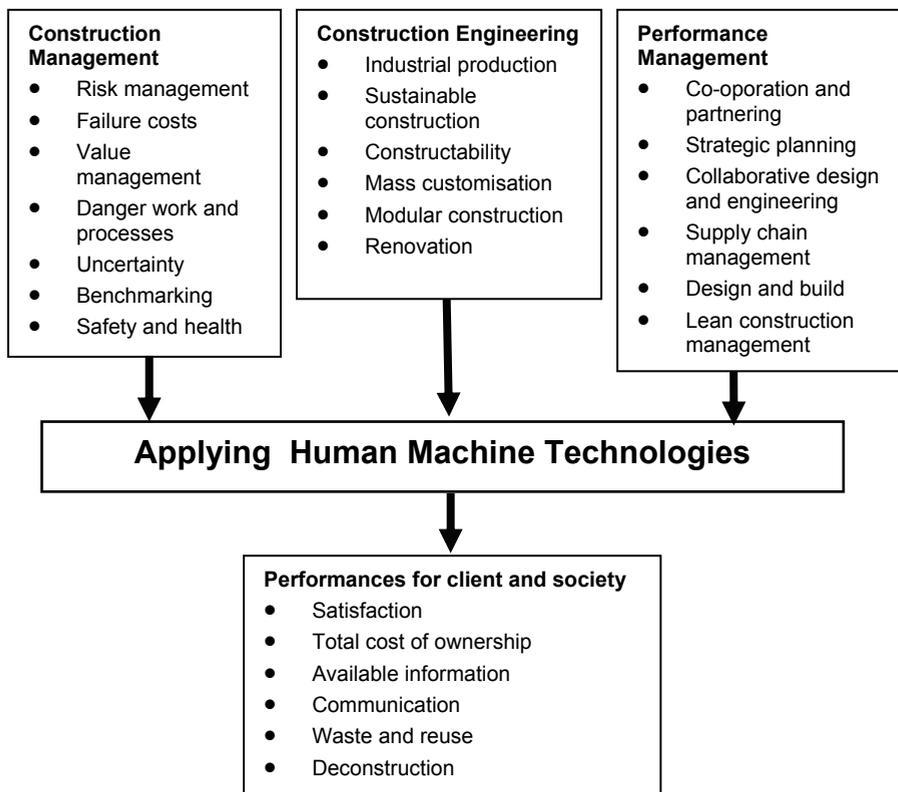- Communication
- Waste and reuse
- Deconstruction

Fig. 2. Relationship between management, engineering and performance (based on Maas & Van Gassel, 2005).

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 with the size of the investment, but are becoming more and more interested in the total cost of ownership and life cycle costs. Nowadays, clients are less concerned with the structure itself. They pay more attention to its functional use, primarily encouraged by the use of information and communication technology in the projects.

Construction engineering has been changed by the application of more industrial production, sustainable construction, mass customisation, and modular construction to improve constructability.

Construction management has to deal with health and safety, uncertainty and danger. Developments are taking place in risk management and value management, supported by partnering, collaborative design and supply chain management.

These developments demonstrate that there is plenty of room for improvement in all process elements of construction projects in metropolises (Maas & Van Gassel, 2005).

4. Worker-equipment system

To produce a building object, three types of task have to be performed: (i) provide strength and energy (physical tasks), (ii) receive and issue information (cognitive tasks) and (iii) make decisions (organising tasks). The human body has a number of suitable parts and society has developed equipment designed to perform the tasks more effectively (see Table 2). As human beings, our speed and power are limited to what equipment can do, but people are far more sensitive to input and have a large, versatile memory.

Tasks	Human body	Equipment
Provide strength and energy	Movement system: muscles lungs	Power tools: energy sources transmissions
Receive and issue Information	Senses: eyes ears voice hands	Telecommunications tools: scanner microphone monitor keyboard
Make decisions	Thought system: brain memory	Computer equipment: computer software artificial intelligence

Table 2. Human body parts and equipment to fulfil tasks.

To perform specific tasks, the process designer chooses the right combination of worker and equipment. Describing such a combination is possible using the basic diagrams of the worker-equipment system (see Fig. 3 and 4).
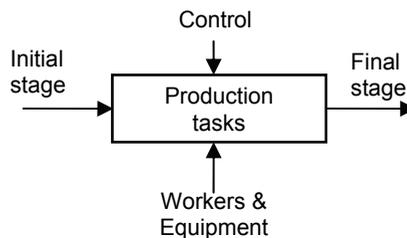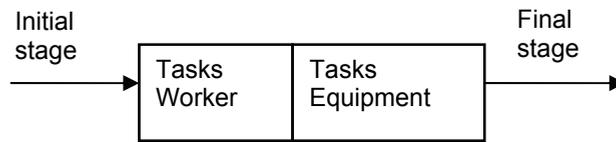

Fig. 3. Basic diagram of the process.

Fig. 4. Basic diagram of the worker-equipment system.

The diagrams used here are based on system analysis. Materials are transformed by the worker-equipment system from an initial to a final situation (Maas, 1991). That part of the tasks to be performed by the equipment and that by the worker are represented by the size of the surface of the rectangle. The rectangles can be divided into activities that can take place in sequence and/or at the same time, so a building activity can be divided into subactivities.

5. Mechanisation and robotisation concepts

The mechanisation concept is defined on the basis of the diagram in Fig. 4: 'Mechanisation is the shift of tasks from worker to equipment'. The concept is shown in a diagram in Fig. 5.
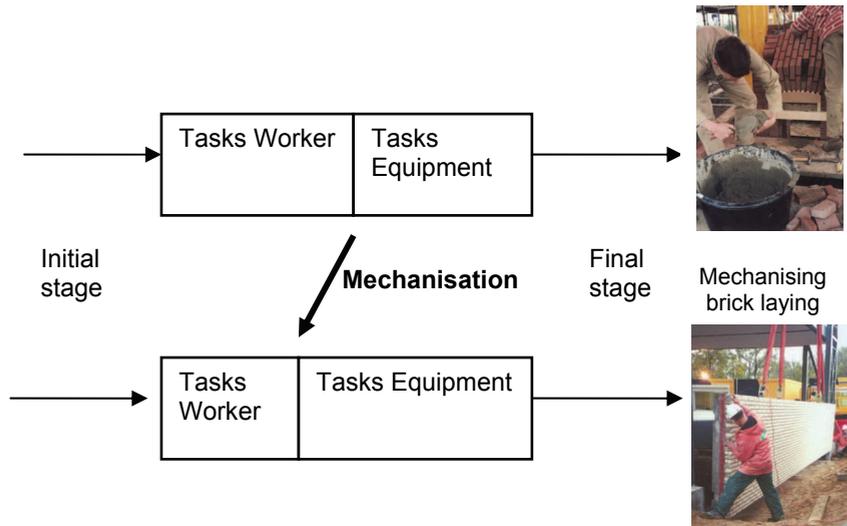
Fig. 5. The mechanisation concept.

Robotisation is a special type of mechanisation in which all tasks are shifted from the worker to the equipment (see Fig. 6). Control and support activities are not included in these tasks, because they are not directly related to the specific production activity.

6. The mechanisation graph

The tasks that workers and equipment carry out can be divided into energy tasks and control tasks.
Three situations are considered for the performance of energy tasks:

1. the equipment does not supply energy
2. the equipment supplies a certain amount of driving energy
3. the equipment supplies all the driving energy and the worker only has to operate the controls.
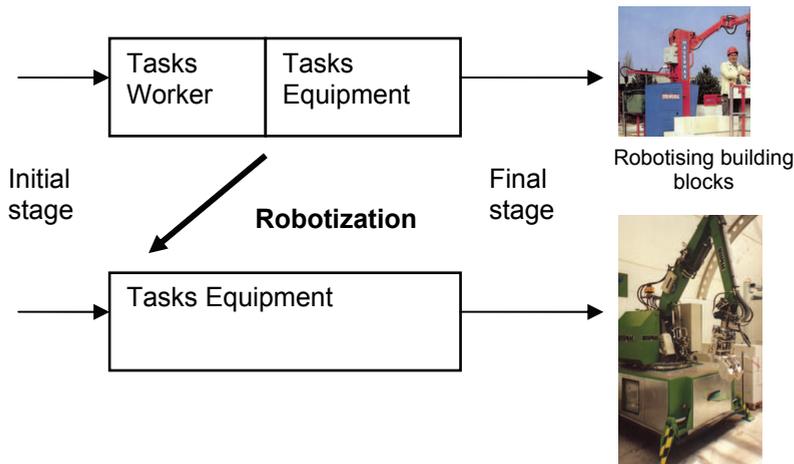

Fig. 6. The robotisation concept.

Driving energy means, for example, the rotating and linear motion of a drill and the supply of energy necessary to hold the equipment in a steady position. The latter can be achieved by placing the equipment on a stand.

The classification of control tasks is based on Guo and Tucker's machine line arrangement (Guo & Tucker 1993). This classification comprises the following levels: hand tools, manually controlled devices, telecontrolled devices, pre-programmed devices and cognitive robots. At the beginning of the line, all tasks are carried out by people, and at the end of the line by machines.

On a graph, energy tasks are placed on the vertical axis and control tasks on the horizontal axis, resulting in a mechanisation graph (see Fig. 7).

A worker-equipment system or elements of such a system can be placed in the squares of the graph.

Examples:

A. The laying of bricks with the aid of a mason's trowel.
B. The drilling of a hole in a wall with an electric drill.
C. The drilling of a hole in a wall with an electric drill that has been placed on a guide and that is started electrically.
D. The riding of an operator on an excavator.
E. The moving of loads with a crane that is remotely controlled.
F. The laying of bricks by a robot that places bricks and mortar according to instructions.
G. The digging of a trench in the ground by an intelligent excavator that can make decisions on the basis of observations.
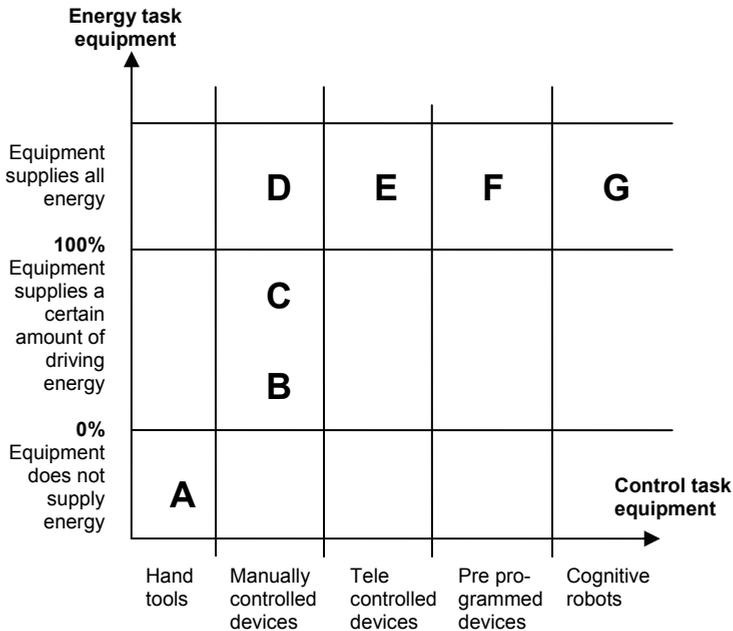
Energy task equipment

	Hand tools	Manually controlled devices	Tele controlled devices	Pre pro-grammed devices	Cognitive robots

Equipment supplies all energy — **D** **E** **F** **G**

100%
Equipment supplies a certain amount of driving energy — **C** **B**

0%
Equipment does not supply energy — **A**

Control task equipment

Fig. 7. Mechanisation graph.

7. Mechanisation phases

It is now possible to indicate the mechanisation phases on the mechanisation graph.
The following phases can be distinguished:
1. optimisation of tools
2. use of drives
3. use of guides
4. use of control equipment
5. use of remote control
6. use of computers
7. use of artificial intelligence

The mechanisation phases are represented in the mechanisation graph in Figure 8. The phases above are based on the mechanisation of existing situations. Entirely new production processes, however, can be designed as well. Here, it is only possible to represent the end of the mechanisation phase on the graph.

An increasing degree of technology is necessary in order to complete the mechanisation phases. This requires knowledge of:
• Materials and construction products
• What workers can do (ergonomics)
• Drive technology, guides and manipulators
• Machine controls, remote controls and programming technologies
• Sensors and artificial intelligence

A chain of mechanisation phases can also be represented on the graph. The smoothing of a poured concrete floor is used as an example. Traditionally, these concrete floors were smoothed with a hand trowel, which involved manually moving the power trowel over the floor. The next mechanisation phase enabled the floor-layer to sit on the machine, so that only operation of the controls was necessary. Next, the machine was equipped with remote control. The machine was then provided with computer controls that can finish the floor according to programmed instructions. The subsequent step would be to provide computer controls that make observations and a number of decisions on the basis of these observations.
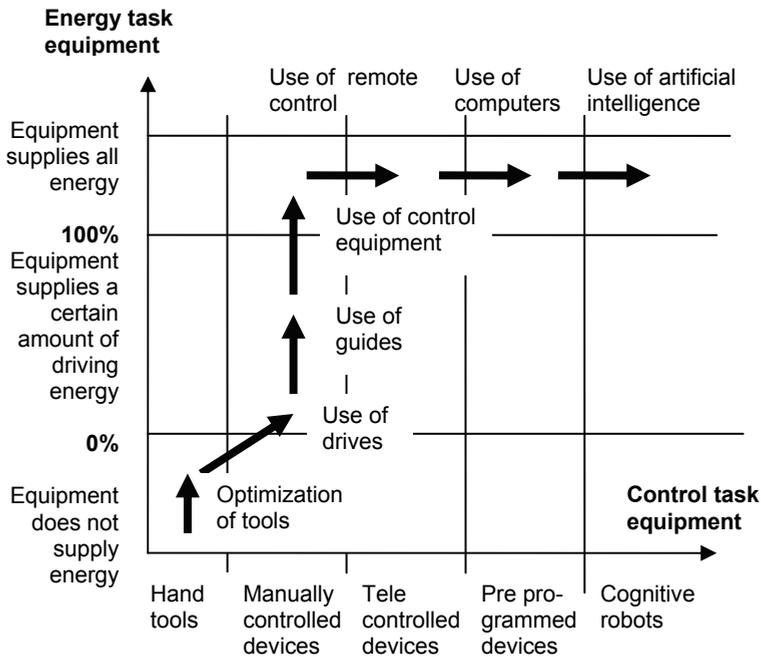
Fig. 8. Mechanisation phases.

A distinction can be made between the mechanisation of production processes of existing products and those of modified or new products. Mechanisation of existing products is the mechanisation of traditional production processes carried out by craftsmen, such as masonry, plastering and carpentry. Generally it is quite possible to mechanise the energy task, while the mechanisation of control tasks is highly complex.

Just analyse the laying of bricks by a bricklayer and try to put these activities in the operating program of a machine. The mechanisation of modified or new products has more of a chance of being put into practice.

8. Example

As an example, the basic diagram is applied to a production process in which large, heavy wall elements are taken from a lorry and mounted on a façade. This can be divided into a number of constituent processes: attachment of the element to the hoisting hook,

transportation to the location where it is to be mounted and turning the element to the desired position (see Fig. 9). The tasks performed by equipment and those performed by people can be described (see Fig. 10).
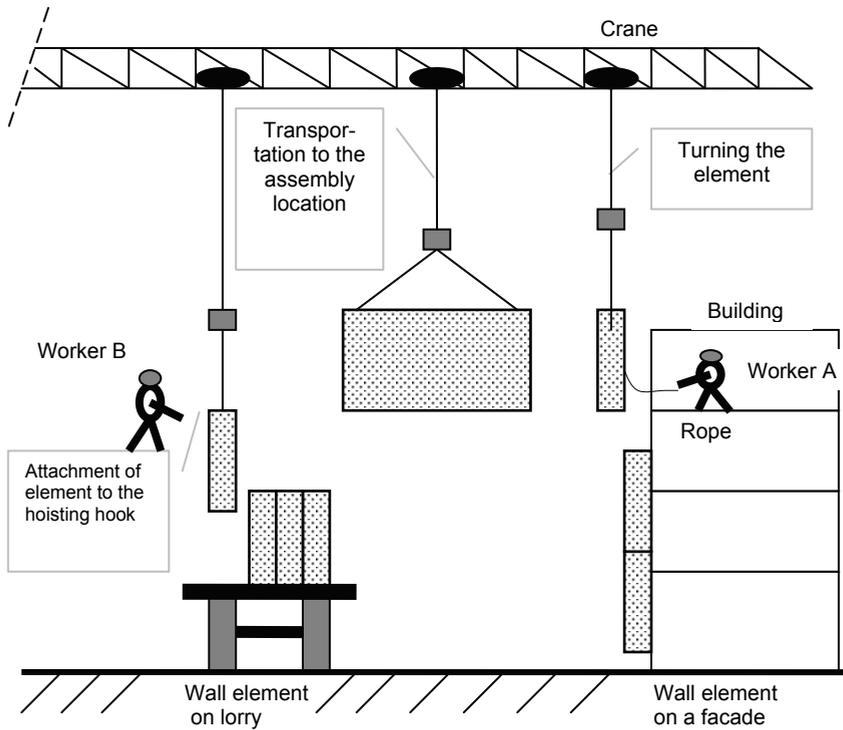

Fig. 9. The mounting of large wall elements.

With the help of technologies, some tasks of worker A and B can be done by equipment (see Fig. 10). For instance, the wall element can be guided automatically by equipment between the hoist hook and the wall element (see Fig. 11 and 12).
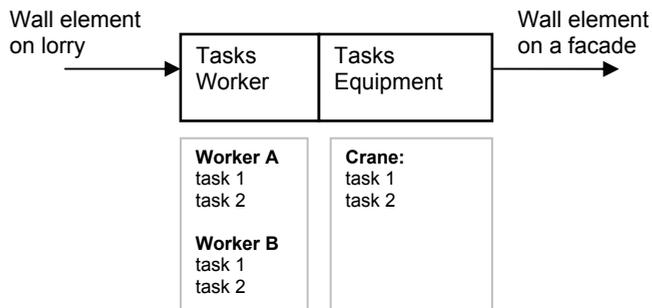

Fig. 10. Analysing the tasks before mechanising.
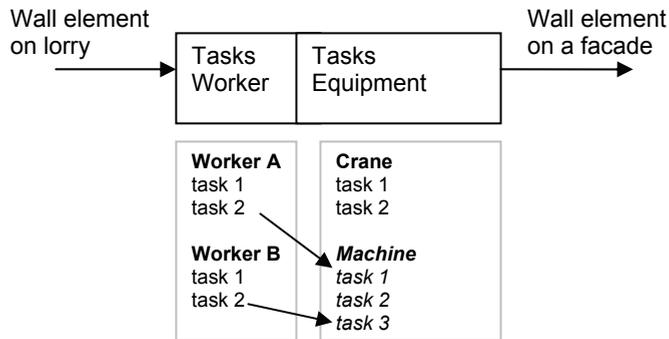
Fig. 11. Desired situation after mechanising.

Fig. 12. Mechanizing the position of a wall element by special equipment.

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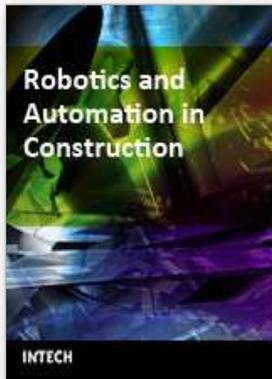
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This book addresses several issues related to the introduction of automaton and robotics in the construction industry in a collection of 23 chapters. The chapters are grouped in 3 main sections according to the theme or the type of technology they treat. Section I is dedicated to describe and analyse the main research challenges of Robotics and Automation in Construction (RAC). The second section consists of 12 chapters and is dedicated to the technologies and new developments employed to automate processes in the construction industry. Among these we have examples of ICT technologies used for purposes such as construction visualisation systems, added value management systems, construction materials and elements tracking using multiple IDs devices. This section also deals with Sensorial Systems and software used in the construction to improve the performances of machines such as cranes, and in improving Human-Machine Interfaces (MMI). Authors adopted Mixed and Augmented Reality in the MMI to ease the construction operations. Section III is dedicated to describe case studies of RAC and comprises 8 chapters. Among the eight chapters the section presents a robotic excavator and a semi-automated façade cleaning system. The section also presents work dedicated to enhancing the force of the workers in construction through the use of Robotic-powered exoskeletons and body joint-adapted assistive units, which allow the handling of greater loads.

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