Ki-NEW-Matics

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Abstract –

Conventional construction reached its limits. Numerous construction projects, such as Cologne subway site causing a billion euro collapse of a library containing cultural heritage assets, the x times cost overruns of Elbphilharmony Hamburg and the x tens of thousands quality defects of Berlin Brandenburg Airport indicate the necessity of an overdue transformation of the whole sector. Automation and robotics in construction could achieve what other manufacturing and service industries have already successfully demonstrated. This article shows how robot oriented design, engineering, management and technologies for the construction and the building sector in a form of a five volume construction robotics handbook series would elevate the industry onto a proper and dignified level of quality and performance, which matches the level of the rest of the manufacturing and non-manufacturing sectors.

Keywords –

Construction Robotics, Automation, Robot Oriented Design, Industrialization, Kinematics, construction quality, building performance, cost overruns, quality defects.

1 Introduction

Welfare and culture in any society can be achieved through sufficient personal income. One nation must be efficient and achieve further productivity and economic growth. Where there are no natural resources to be exploited and sold, high income can only be accomplished by sophisticated technology. Affordable and efficient socio-economical and socio-technical processes are further required by the demographic change. Half of the total investment is allocated in the built environment, infrastructures and facilities, signifying the strategic importance of the construction sector.

Productivity in the construction industry has been declining for decades world-wide. The construction industry has one of the lowest capital stocks compared to other industries, as well as low capital intensity. Furthermore, construction defects, improper working conditions and low interest in the construction field for younger generations, as well as the tremendous consumption of raw materials and energy by the construction process and building products, state challenges for which conventional construction and the architecture industry currently do not have solutions for it. In high wage countries, the natural ageing of societies will continuously aggravate the situation by reducing our human capital, as well as the ability for change and economic growth. Börsch-Supan, a German macroeconomist, predicts a solution for augmenting productivity and economic wealth, therefore, predominantly in supplementing human capital by capital intensity, non-linear advances in machine technology and productivity (Börsch-Supan et al, 2009)

General manufacturing under the notion of "Industry 4.0" (see for example Jopp, 2013) or "Cognitive Factory" (see for example Zäh et al., 2009) as hyper-flexible and intensively automated manufacturing systems (also considered already as the 4th industrial revolution) in which highly autonomous, flexible and distributed but still networked automation and robot systems cooperate together in producing in a nearly real-time manner individualized and complex products with incredible productivity could offer in construction industry higher productivity and needed change, that has been stagnating for decades. Innovation in construction industry occurs extremely slowly. The reason for that, from one side is caused by the characteristics of the products and their complexity, long life-cycle, diversity, dimensions, materiality and fixed site nature. Additionally, it has its roots in the low R&D budgets and the reluctance to new strategies and technologies. Opposed to the marginal improvements in conventional construction, since the 1970s scientists, R&D departments and innovative companies supported by universities, associations and governmental institutions, pursued on a consistent manner, a new set of technologies and processes which will change the whole course and idea of construction in a fundamental way and which can be summarized under the term "Automated Construction". (Figure 1, Table 1) Represent the idea as a whole

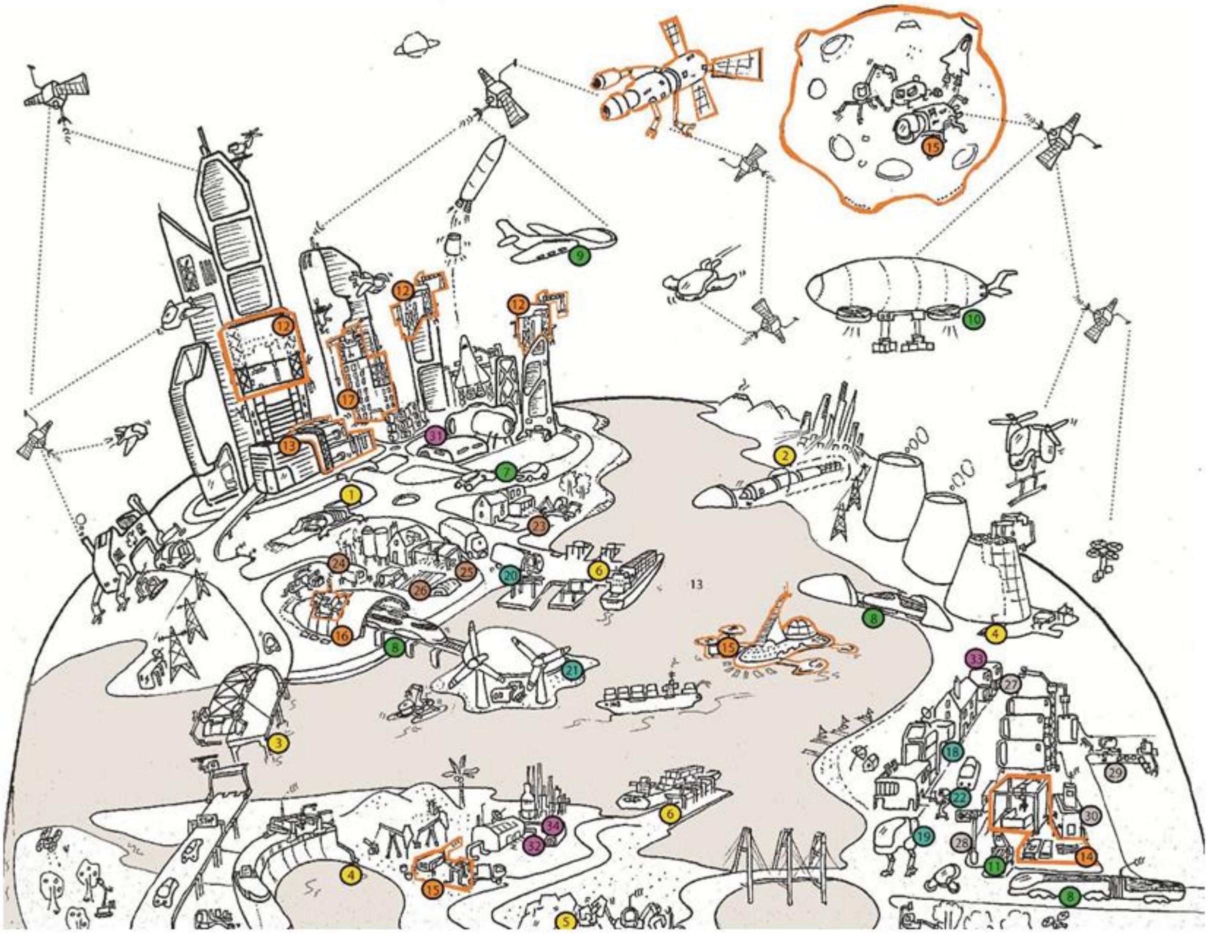

Figure 1 Automation and robot technology becomes ubiquitous and step by step pervades our life on earth. In our volume series the focus is set to, but not limited, to Automated/ Robotic Construction

In contrast to conventional construction, Automated Construction is capital intensive and machine centred while, being potentially limitless in performance and capable of real-time manufacturing. As Automated Construction necessitates a complementary and also disruptive change in the whole industry (products, processes, organisation, management, stakeholders, business models, etc.) in order to be able to fully unfold its potential, it can be considered as a rather complex type of innovation or change.

Changes of such complexity takes time, sometimes decades. However, now after nearly 40 years of technical development and experimenting in the field, the result is increased activity within companies, research institutes, associations and governmental institutes. This indicates that this new trend gains in acknowledgement, the adoption of future technologies and finally being able to head towards a growth phase.

Table 3: Thematic fields into which automation and robotics is currently advances

Thematic Field		Systems and Approaches
Automated/ Robotic Infrastructure Production	1	Automated road construction
	2	Automated tunnelling (i.e. by TBMs)
	3	Automated bridge construction
	4	Automated con- and deconstruction of dams, power plants, etc.
	5	Automated mining
	6	Automated container port
Automated/ Robotic Transportation Systems	7	Autonomous cars
	8	Autonomous public transport (U-Bahn, Train, etc.)
	9	Autonomous air travel
	10	Automated logistics
	11	Advanced micro-mobility (i.e. Cyberdyne's HAL or Toyota's i-Real)
Automated/ Robotic Construction	12	Automated construction of vertically oriented buildings
	13	Automated construction of horizontally oriented buildings
	14	Housing production
	15	Novel construction Markets accessible through automated/robotic construction:
	16	Automated Building Servicing and Maintenance
	17	Automated De-construction and re-customization
Automated/Robotic Environments	18	Home & Office Automation
	19	Assistance Technologies and Human-Ambient-Technologies
	20	Networked Production Facilities and Supply Networks
	21	Intelligent Energy Generation and Distribution
	22	Service and household robotics
Automated/ Robotic Farming and Food Production	23	Computer Aided/ Robotic Farming
	24	Robotic Milking Stanchions
	25	Automated Food Production Facilities
	26	Customized Food
Automated Robotic Town Management	27	Smart Grids
	28	Automated/ Robotic Traffic Control
	29	Automated/ Robotic Infrastructure Inspection and Maintenance
	30	Automated Supply Management (water, gas, goods, food, etc.)
General Manufacturing Industry	31	Digital/ Cognitive Factories
	32	Mass Customization
	33	Mini Factories, Cloud Manufacturing
	34	Cellular Logistics

2 Transformation towards Advanced Construction and Building Technology: Robot Technology Becomes Ubiquitous

"The end of the information age will coincide with the beginning of the robot age. However, we will not soon see a world in which humans and androids walk the streets together, like in movies or cartoons; instead, information technology and robotics will gradually fuse so that people will likely only notice when robot technology is already in use in various locations."
Ishiguro (2012)

Robotic systems are an advanced classification of machines characterized by their capabilities, such as re-programmability, autonomy, flexibility and situational awareness. By observing advances within robot technology, it is feasible to predict that robot technology will experience a similar development as did the personal computer during the nineties. Experts and masterminds, as for example Bill Gates, announce the era of robotics and estimate that robotics of our everyday life. The South Korean government recently announced that it supports heavily the development of robot technology having the goal to establish at least one robot system in each household. In 1961 Joe Englberger already wondered, whether relating robotic technologies to only product manufacturing applications makes any sense. "The biggest market will be service robots" (**Englberger, 1989**) asserted Englberger, who started the industrial robotics era, when his firm (Unimation) delivered GM's first robot.

Currently robots are becoming more user friendly, less expensive, task adaptable, smaller, more widely distributed and seamlessly integrated into work processes and devices. Individuals today are able to acquire modular kits of open source robot hardware, and interface robot systems directly to a computer via USB devices. The modern options make transitions between self-contained devices, such as the classical 6-DOF industrial robots, much more simplistic. Currently these types of machines, automation systems and robotic technology, are advancing in such a way that the differences are becoming seamless. There are examples of Robots which have become no longer visible. The complexity of Robots consists of a network of interconnected, distributed and sometimes invisible sensor and actuator systems (including mobile phones or appliances). This means that individual devices functioning as machines can cooperate as a network to manipulate or achieve goals (by manipulating energy flows as smart grids do) autonomously as a robot system.
With the continuous evolution within the field of Robotic
Research, new technical capabilities (modularity, lightweight concepts, wearable robot technology, and social robot technology) have been explored and combined with existing manipulation oriented automation, and robot technology.

Over time, the ability of robot systems has grown, allowing them to work more and more in comparably unstructured environments, to those in which human beings operate. This evolution leads to the fact that robot technology, apart from the classical manufacturing industries, can now be introduced and be

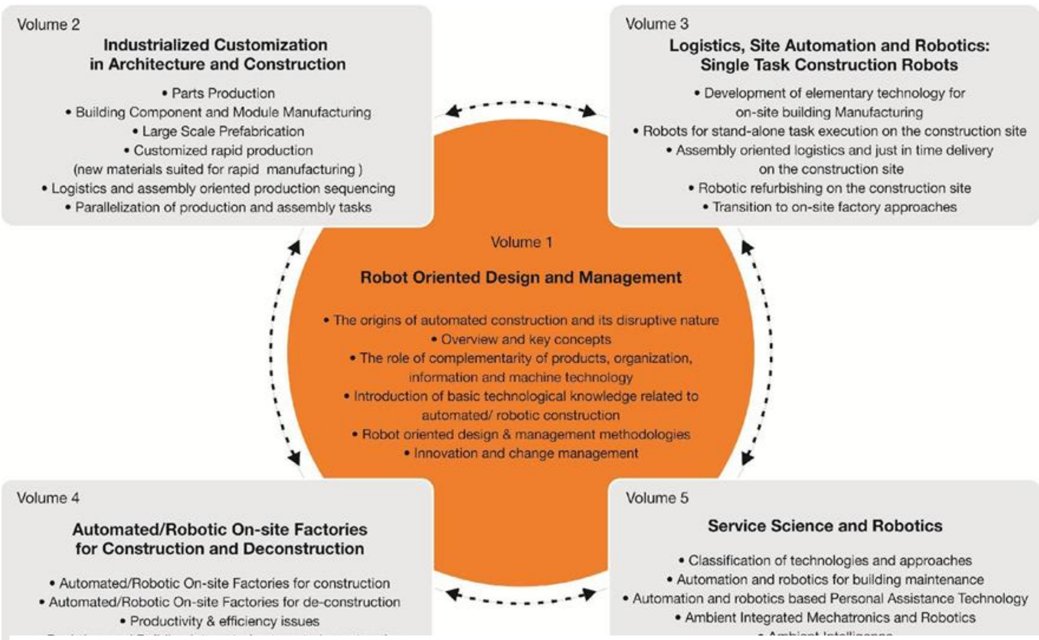

Figure 2. ACBT Covers following thematic fields which are outlined in 5 complementary Volumes

deployed in numerous fields, such as aircraft production, farming, the construction industry and health care sector. New capabilities not only extend the application area of robotics, but also allow robot systems to be used in factory-like environments. This provides robot systems the ability to become more dexterous and adaptive, sequentially building a basis for the production of customized and individual products. Faster product life cycles, and the increasing demand for flexible production systems able to produce customized products, has also lead to refined modularization, plug-and play capabilities of subsystems, open source approaches, concepts for self-configuring and self-organizing robot systems and cellular robotic logistics.

In short it can be said that automation and robot technology becomes ubiquitous, and step by step pervades our life on earth lists thematic fields into which automation and robotics is currently advancing as well as approaches and systems within those fields. It shows that nearly all field of professional and private life are subject to the pervasion of robot technology. It can be assumed that with full establishment of automation and robotic in some thematic fields will follow in order to exploit complementarities and synergies. (Figure 2).

3 New Design and Management and Movement by Robot Oriented Design (ROD)

New design, innovation and management methodologies that are keys for the realization and implementation of the advanced concepts and technologies are explained by Robot oriented design in Volume 1, industrialized customization in Volume 2, Single Task Construction Robots in Volume 3, and automated on-site factories in Volume 4 and ambient integrated robotics in Volume 5. Robot Oriented Design and Management enable the efficient deployment of advanced construction and building technology. It is concerned with the co-adaptation of construction products, processes, organisation and management and automated or robotic technology, so that the use of such technology becomes applicable, simpler or more efficient. It is also concerned with technology and innovation management methodologies and the generation of life-cycle oriented views related to the use of advanced technologies in construction and building context. The concept of ROD was first introduced in 1988, in Japan by **Bock (1988)** and served later as the basis for automated construction and other robot-based construction sites around the world. (Figure 3) It was developed for improving the construction sector and adjusting conventional construction processes and component design to the needs of the novel tools.

In Volume 1, technologies relevant to understanding approaches outlined in Volumes 2, 3, 4 and 5 and the evaluation of related technical, organizational and economical concepts and parameters are introduced. Volume 1 also contains the core glossary, which provides the explanation of concepts, terms and acronyms relevant for all 5 volumes.

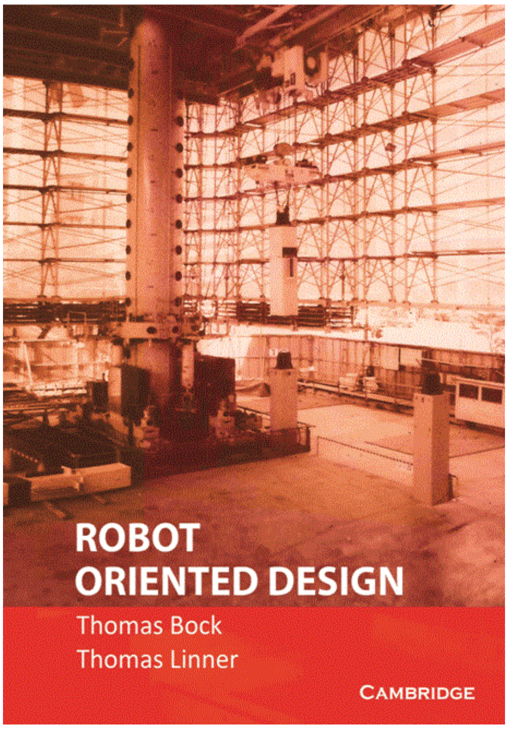

Figure 3. Robot Oriented Design

4 Ki-NEW-Matics in Industrialized Customization – Automation and Robot Technology in Component, Module and Building Prefabrication

For industrialized customization, concepts, technologies and developments in the field of Building Component Manufacturing (BCM) based on concrete, brickwork, wood, and steel as building materials and Large-scale Prefabrication (LSP) holding the potential to deliver complex components and products are introduced and discussed. BCM refers to the transformation of parts and low-level components into higher level components by highly mechanized, automated or robot supported industrial settings.

The definitions of components are interpreted differently by different industries and even by individual companies. However, the definitions of components share a common element, that they are a more or less a complex combination of individual pre-existing parts and/or lower level components. Pure BCM can be distinguished from the transformation of raw material, into parts (production of bricks or simple concrete blocks).

Also, component manufacturing can be distinguished from the manufacturing of highly complex modules or units. BCM is clearly distinguished from the manufacturing of high-level building blocks, such as building modules (prefabricated bath modules or assistance modules which can also be referred to as building subsystems) and building units (such as the LSP of fully finished three-dimensional building sections, like Sekisui Heim, Toyota Home, Pana Home, Misawa Hybrid). For highly automated LSP, according to the OEM model, component manufacturers represent Tier-1 or Tier-2 suppliers. Tier-1 suppliers would deliver components directly to companies such as Sekisui Heim, whereas, Tier 2 suppliers would supply the suppliers of the bath or assistance units. For Automated/Robotic On-site Factories, component manufacturers again represent Tier-1 or Tier-2 suppliers. BCM and LSP industry can reduce on-site complexity and build the supply backbone in an OEM-like industry structure, which can be considered also as a prerequisite for the successful implementation of Automated/Robotic On-site Factories. (Figure 4)

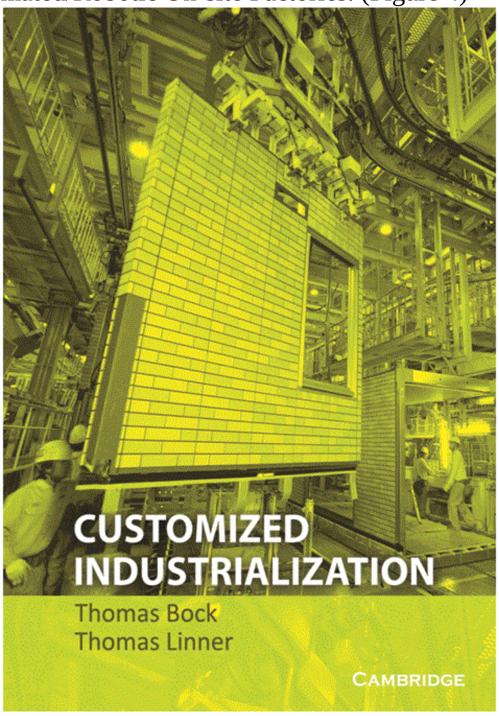

Figure 4. Customized Industrialization

5 Ki-NEW-Matics in Single Task Construction Robots (STCRs)

After the first experiments in large-scale industrialized, automated and robotized pre-fabrication of system houses were conducted successfully in Japan, and the first products (e.g. Sekisui M1) also proved successful in the market, the main contractor Shimizu, 1975 in Tokyo, set up a research group for construction robots.

The goal was now no longer the mere shifting of complexity into a SE as in LSP, but the development and deployment of systems, which were able to be used locally on the construction site to create structures and buildings. The focus initially was set on simple systems in the form of STCRs that can execute a single, specific construction task in repetitive manner. The fact that STCRs operated task specific made them initially highly flexible (they could be used along with conventional work processes and did not necessitate that the whole site is structured and automated), but also represented a major weakness. As they were, in most cases, not integrated with upstream and downstream processes, which demanded safety measurements and hindered parallel execution of work tasks by human workers in the area where they were operated, productivity gains were often equalized. Above all, the set-up of the robots on-site (equipment, programming) was time consuming and demanded new skills. In addition, the relocation of the systems on-site was, in many cases, complex and time consuming.

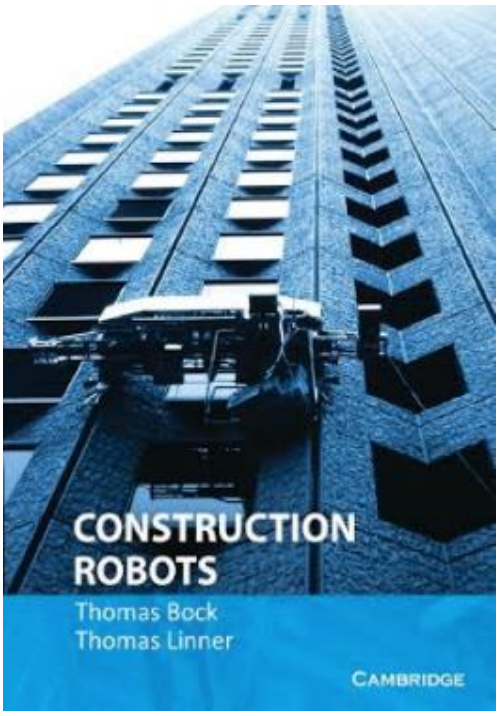

Figure 5. Construction Robots

The evaluation of the first generations of developed and deployed STCRs and the identification of the above mentioned problems led step-by-step from 1985 onwards to the first concepts for integrated automated/robotics sites. Concepts for Integrated automated construction sites integrated STCRs and other elementary technology as subsystems into and SE set up on the construction site. The development of STCRs, elementary technology, and a concept for structuring on-site environments by ROD was analysed and supported by Bock (Figure 5) from 1984 to 1989 (**Bock, 1988**). As the development of STCRs, elementary technology and alternatives created the basis for, and paved the way for the realization of integrated automated/robotic construction sites from the 1990s onwards. Furthermore, as the development of STCRs, parallel to or as subsystems of integrated automated construction sites continued up to today, 140 STCRs have been identified, analysed and categorized. In this volume, the conceptual and technological reorientation towards integrated automated construction sites initiated by WASCOR Group, WASeda Construction Robot Group and joined researchers of all major Japanese construction firms and equipment is shown.

6 Ki-NEW-Matics in Automated/robotic On-Site Factories for Construction and Deconstruction

The approach of setting up SEs on the construction site in the form of Automated/Robotic On-site Factories can be considered as a logic taking further of BCM, LSP
(Volume 2) and STCRs (Volume 3) technology.
In Volume 4, all worldwide conducted approaches following the above set direction to an on-site factory approach are outlined. 30 different systems are identified, resulting in an application of Automated/Robotic On-site Factory technology about 60 times. The outline is split into a more technical part and a part which focuses on parameters related productivity, efficiency and economic performance. All systems were outlined systematically and based on the same frameworks and 13 categories were set up (ten categories for construction and three categories for deconstruction). One of the main ideas for setting up automated on-site factories was to integrate stand alone or STCR technology into structured on-site environments to networked machine systems and to improve organization, integration and material flow on the construction site, apart from the possibility to off-site manufacture components. Automated On-Site factories show for which building typologies Automated/Robotic On-site Factories are an applicable approach, and how and to extent those systems can be made technologically flexible in order to be able manufacture a variety of different buildings (products) on the basis of industrialized, automated and flow-line like stable factory processes. Also, it is shown how, in contrast to the STCR approach, the approach of setting up Automated/Robotic On-site Factories is capable of achieving a performance multiplication ,which usually accompanies the switch from arts and crafts based manufacturing, to machine based manufacturing.(Figure 6)

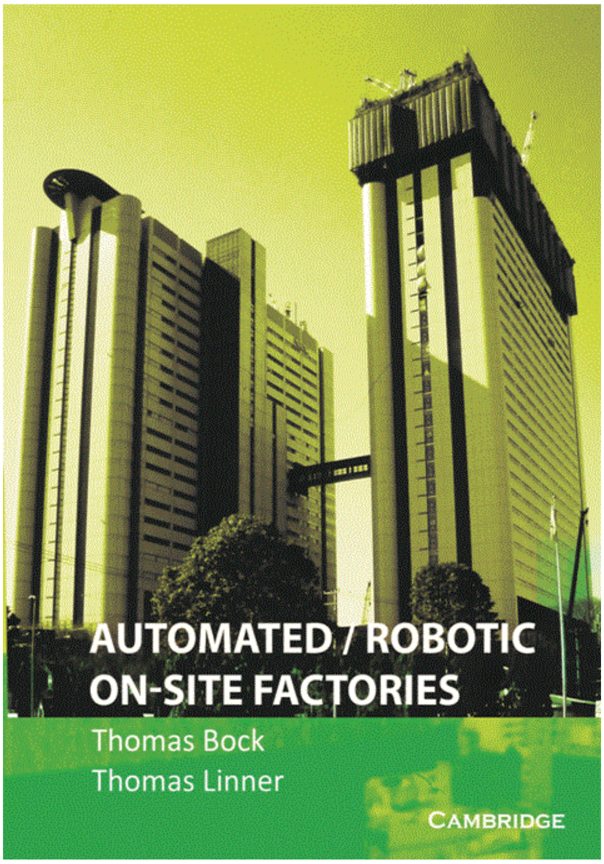

Figure 6. On-Site Factories

7 Ki-NEW-Matics Example 5: Ambient Integrated Robotics - Automation and Robot technology in building maintenance, assistance and service

For a long time the focus of innovation in the area of automation and robotics in construction has been laid on the industrialized and rationalized off-site or on site construction as well as on related processes, building systems, management and logistic tools and high-tech construction and prefabrication robotic equipment.

Still today, the complexity of buildings continues to rise rapidly due to new paradigms as Ubiquitous Computing, the demand for energy efficiency and emerging assistance technologies. Buildings become integrated with a multitude of new sub-systems and extend their performance to areas which have formerly not been accounted as being part of construction and building industry, yet, which now gradually merge with our built environment. With the integration of Microsystems Technology into buildings, and due to the tendency towards more and more user integration (**Piller, 2006**), buildings become not only more intelligent, but they can be much more personalized to the inhabitants needs and could further serve as platforms for a multitude of continuous and commercial services. These changes could have a tremendous impact on the whole value chain and are likely to transform building structures, construction technologies and business models. (Figure 7).

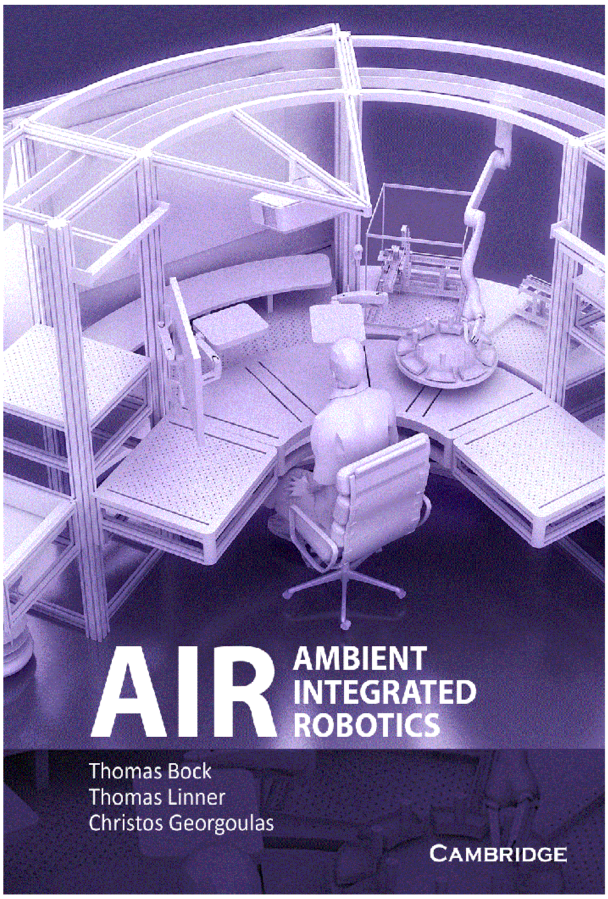

Figure 7. Ambient Integrated Robotics

8 Conclusion

The five examples of Ki-NEW-Matics are based on the Greek meaning of motion and movement. The existing problems and defects of the construction sector can be successfully addressed by introducing advanced construction and building technology based on automation, robotics and services. This new movement will lead to an innovation leap.

References

[1] Automation in Construction, An international research journal, Vol. 12 Number 4 July 2003, 12(4) 349-464 (2003)

[2] Bock, T. (1989) ‘Robot Oriented Design’ [Dr.-Ing. Dissertation], Faculty of Engineering, Chair of Building Production. The University of Tokyo.

[3] IAARC (1998) ‘Robots and Automated Machines in Construction’, Watford: International Association for Automation and Robotics in Construction

[4] Linner, T. (2013) ‘Automated and Robotic Construction: Integrated Automated Construction Sites’ [Dr.-Ing. Dissertation], Technische Universität München – in particular chapters 1, 3 and 4 in this Volume (**Volume 3**) are based on chapters 4 the thesis; furthermore the classification system for the STCRs has been adopted from the thesis and expanded and detailed in this volume (**Volume 3**).

[5] Piller, F. T. (2006). Mass Customization als wettbewerbsstrategisches Konzept. *Mass Customization: Ein wettbewerbsstrategisches Konzept im Informationszeitalter*, 153-236.