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The future of construction automation: Technological disruption and the upcoming ubiquity of robotics

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ABSTRACT

The following article reviews past and current tendencies and derives and describes opportunities for future construction automation that go beyond the current notion of construction automation. Various indicators suggest that conventional construction methodology has reached its limits. An overlay of S-curves can be used to describe the relationship between the stagnation and technical limits of conventional construction and the initiation, development, and growth of new strategies and technologies of construction automation. Although approaches of construction automation are still in an innovation or seed phase, it can be expected that with continued effort put into research and development these approaches may soon enter into the growth phase and encounter adoption on a larger scale. Furthermore, the article shows that over time, the ability of robot systems has grown, allowing them to work more and more in comparably unstructured environments as well as to be deployed in numerous and diverse fields. Currently, it can already be observed that construction automation technology, STCR approaches, service robot systems, and other microsystems technology are merging with the built environment, becoming inherent elements of buildings, building components, and building furniture.

1. Introduction

Every nation values efficiency in order to achieve as well as to sustain productivity and economic growth. Where there are no natural resources to be exploited and sold, high economic sufficiency can only be accomplished via sophisticated technology. Moreover, affordable and efficient socio-economical and socio-technical processes are also required by age-related demographic change. It is estimated that half of a nation's total investment is allocated to the built environment, viz., infrastructures and facilities, signifying as well as emphasizing the strategic importance of the construction sector. Studies strongly suggest that productivity in the construction industry has been declining in recent decades worldwide (see Fig. 1). The construction industry has one of the lowest capital investment as well as low capital intensity compared to other industries. Moreover, inappropriate working conditions—may these be related to sub-par human conditions or to technological inadequacies—as well as a low interest in the construction sectors shown by younger generations, the tremendous consumption of raw materials and energy (see Fig. 2) by the construction process and building products, etc., represent challenges for which conventional construction and architecture industries currently do not have solutions for. Furthermore, defect rates, cost overruns, and the ineffective as well as inefficient effort put into management strategies [1] to encounter these issues suggest that conventional construction has reached its possible technological performance limit [2].

In highly developed nations, the natural ageing of societies will continuously aggravate the situation by reducing human capital as well as the ability to implement change and boost economic growth. To ameliorate the situation, Börsch-Supan—a German macroeconomist—proposes a solution for augmenting productivity and economic wealth predominantly by supplementing human capital with capital intensity, non-linear advances in machine technology, and productivity [5]. Strategies coming from general manufacturing industries under the notion of “Industry 4.0” (see for example [6]) or “Cognitive Factory” (see for example [7]) call for hyper-flexible and intensively automated manufacturing systems (also considered as the 4th industrial revolution)—in which highly autonomous, flexible, and distributed but still networked automation and robot systems cooperate together to produce in a near real-time manner individualized and complex products with consistently sustained productivity—that promise higher productivity and needed change in a construction industry that has been stagnating for decades. Innovation in construction industry occurs extremely slowly. One of the key reasons for this is the involved multi-faceted characteristics of the products and their complexity, long life-cycle, diversity of dimensions, and materiality, as well as the fixed-site nature of construction. Additionally, the low R&D budgets and the industry's reluctance to adopt new strategies and technologies represent a *de facto* limitation. In opposition to the marginal improvements in conventional construction, since the 1970s, scientists, R&D departments, and innovative companies supported by universities, associations, and governmental institutions consistently pursued a new set

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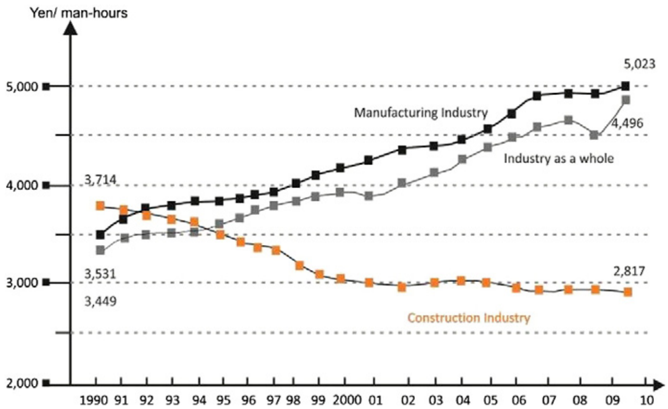

Fig. 1. Labor productivity in industry generally, and especially in the manufacturing industry is continuously rising; labor productivity in construction has been decreasing for decades (image based on [3,1]).

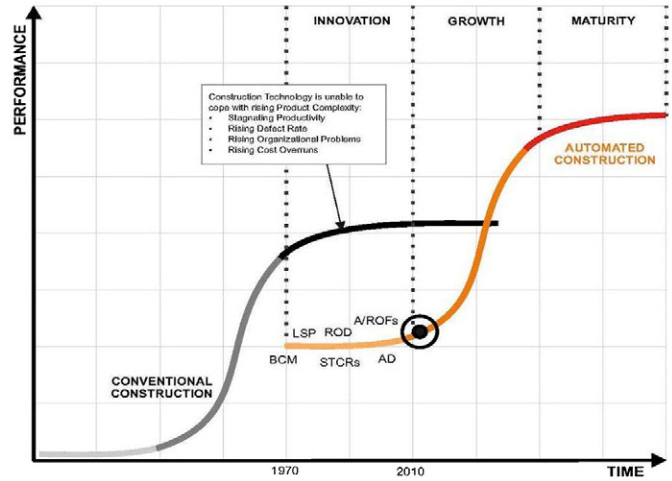

Fig. 3. Foster's (1986) S-curves applied to construction. BCM = building component manufacturing, LSP = large-scale prefabrication; STCRs = single-task construction robots; ROD = robot-oriented design; A/ROFs = automated robotic on-site factories; AD = automated deconstruction) [2].

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 "construction automation" (CA).

The existing problems and defects of the construction sector can be successfully addressed by future CA. An overlay of S-curves [8] can be used to describe the relation between the stagnation and technical limits of one technology (conventional construction) and the initiation, development and growth of new strategies and technologies (future CA), which are at the beginning inferior to the existing technology but gain in importance, performance, and adoption rate over time (Fig. 3, [2]).

Conventional construction gives birth to new technologies, which at the beginning phase (where we presently find ourselves) are inferior in performance due to technical, organizational, and economical obstacles as well as to limited integration within an economic environment still dominated by mature and conventional technology. However, predictions based on analyses of current trends demonstrate that new technologies will outperform the conventional ones over time. Currently, it can already be observed that CA technology, STCR approaches, service robot systems, and other microsystems technology are merging with the built environment, becoming inherent elements of buildings, building components, and building furniture. Over time, the ability of robot systems has grown, allowing them to work more and more in comparably unstructured environments as well as to be deployed in numerous and diverse fields. Robot technology becomes ubiquitous and starts pervading life and built environments. Since this diffusion of robot technology is in most cases strongly linked to the built environment, future activity fields for CA will derive from this.

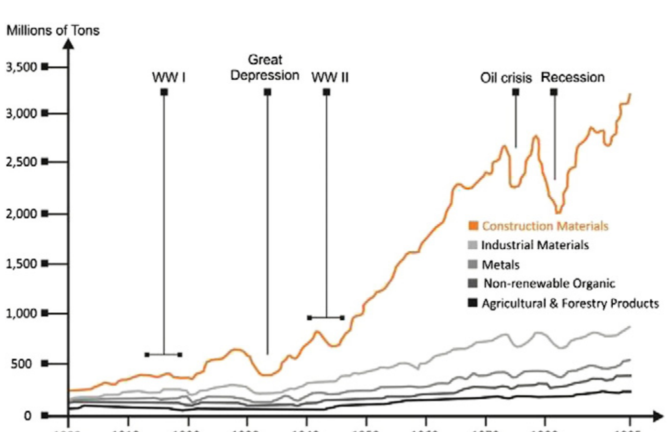

Fig. 2. Raw material consumption (short tons) in the United States 1900–1995 (image based on [4,1]).

In contrast to conventional construction, CA is capital intensive and machine centered while being potentially limitless with respect to performance and capable of real-time manufacturing [1]. As CA necessitates a complementary and also disruptive change industry-wide (products, processes, organization, management, stakeholders, business models, etc.), it can be considered as a rather complex type of innovation or change as to allow it a pertinent developmental depth and breadth in order for it to fully unfold its potential. Changes of such complexity take 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 and the adoption of the future technologies involved become increasingly acknowledged and accepted, which allows it to head toward a growth phase. Bock and Linner [2] categorized new design, innovation management methodologies, and enabling technologies that are essential to the realization and implementation of future CA as follows: (1) robot-oriented design, (2) robotic industrialization, (3) construction robots, (4) site automation, and (5) ambient robotics. The following sections summarize and outline these key concepts and show how future technological disruption could be implemented as well as how construction robotics might finally diffuse into a variety of areas of life.

2. Robot-oriented design: design and management tools for the deployment of automation and robotics in construction

Robot-oriented design (ROD) and management enable the efficient deployment of advanced construction and building technology. It is concerned with the co-adaptation of construction products, processes, organization and management, and automated or robotic technology, so that the use of such technology becomes applicable, simpler, and/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 (see also Fig. 4) was first introduced in 1988 in Japan by Bock [9] and served later as the basis for automated construction and other robot-based construction sites around the world. It was developed for improving the construction sector and adjusting conventional construction processes and component design to the needs of the novel tools [2].