Industrialisation and Automation of the Building Process
The introduction of robotics in construction is part of a much longer history of industrialisation and automation on the building site. Thomas Bock of the Technical University of Munich and Silke Langenberg of the University of Applied Sciences, Munich, highlight how the Industrial Revolution and the development of a transport infrastructure in the 18th and 19th centuries in Europe first triggered the shift in the building trade from a largely localised industry into a national and mechanised one, leading to the highly advanced automated construction techniques that continue to be developed in Japan and other Asian countries to this day.

The Industrial Revolution changed the building process, by then largely dependent on a local base of materials, skills, building knowledge and tradition, irrevocably. In the late 18th century and throughout the 19th century, new machinery, serial-produced elements and industrially fabricated materials started to appear on building sites, complementing long-term approved construction techniques. It was not, however, until the 20th century that there was a real attempt to adopt industrial manufacturing processes. By the 1920s and 1930s a few prototypical buildings had been realised, anticipating the so-called ‘industrialised construction’ processes that were rolled out at a larger scale during the second half of the century: from the serial prefabrication of building elements to the mass production of standardised housing estates and system buildings. The specialised robotic machinery and automated high-rise construction sites that were developed in Asia during the 1990s can be viewed in the context of a greater trajectory of mechanisation and industrialisation.

The beginning of the 21st century could again prove pivotal for the building process, with robotic fabrication having the potential to change the building site once more. On that account, it seems crucial to take a look at the development, influence and results of some historical precursors in order to understand that the implementation of robotics in architecture at a larger scale may not just require a first phase of experimental research and prototyping, but also a fundamental change in the early design stages as well as in the construction process that goes far beyond imitating existing building technologies.
The Establishment of Industrially Produced Elements and New Materials

The mechanisation that was a consequence of the Industrial Revolution has, by the expansion of the railway networks, thus increasing mobility and transportation of goods and materials, directly resulted in the growth and congestion of industrial towns, and the fast development of their building stock and infrastructure. It has also directly affected the building industry and construction process: industrially produced materials and prefabricated building elements such as cast-iron beams and columns, glass, factory-made bricks or artificial stone decorative elements were increasingly used during the 19th century, and their potential in the erection of large industrial, infrastructural and representational buildings explored. Different construction techniques were thus required, and specially developed building machinery and cranes began to change the organisation of the building site:1 the construction of the Crystal Palace for the Great Exhibition in 1851, for example, required a whole series of different machines, powered by a steam engine.2

As a large number of identical or similar parts were essential for making industrial fabrication and serial production economically viable, the number of different building elements was reduced. At the same time their lot size was further increased by using them en masse for the erection of large building volumes. Thus the application of industrially mass-produced building elements first manifested itself in the construction of large-scale steel structures – bridges, train stations, towers, exhibition halls, the glass roofs of galleries and department stores – which were assembled from a manageable amount of columns and beams in available standardised cross-sections. Around the middle of the 19th century, concrete also gained in importance as a result of the industrial production of Portland cement.

By the beginning of the 20th century, the general availability and usability of serial mass-produced building elements in steel and concrete, combined with opportunities to transport them over longer distances, made the use of prefabricated elements much more common even in smaller individual buildings. However, the architectural design of the numerous town houses and office buildings constructed during that time rarely represented the use of industrially produced materials or components, which had somehow simply become state of the art.

Rationalisation and Industrialisation of the Building Process

The building industry started to adopt industrial production methods during the 1920s and 1930s in a push to solve the housing shortage in the growing towns after the First World War: The design of a limited number of identical building elements to construct slightly different housing types aimed to enable serial mass production and time and cost savings akin to those realised in other sectors of industry. At the same time there was an attempt to reduce and simplify the number of stages involved in building on the construction site, to increase the employment of unskilled labour and to shorten the completion time. Walter Gropius's Törten housing estate in Dessau, Germany (1928) is maybe one of the best-known examples,3 along with the Hausbaumaschine ('House Building Machine') developed and published during the Second World War by Ernst Neufert.4 This process-oriented initiative differed completely from the approaches of the 19th century in its ambition to change the organisation of the building site instead of just responding to, and borrowing from, the innovations and products developed by other sectors of industry.

The ideas behind the rationalisation of the production of building elements and industrialisation of the building process were first propagated in Europe after the Second World War, when there was a concerted effort to realise them at a larger scale. For the first time the serial mass-production of elements and use of industrial fabrication methods in the building industry seemed to make sense, because of the tremendous amount of buildings required to meet the urgent task of reconstruction and demand for housing in the postwar period, as well as during the following boom years between 1950 and 1970.
Industrialisation of building: this seems … to be the keyword, in which direction the building industry has to develop. In our technical age houses should arise like products in a factory … The engineered work of ‘house production’ is most distinctively possible in a factory. But also the building site can largely be attuned to it.

— Günther Gottwald, 1951
While in the 1950s building construction remained quite conventional, with advances largely limited to the use of new materials – plastics, aluminium and composites – as well as larger and stronger machinery, by the 1960s and 1970s a distinct change had come about in the design process. Standardised buildings and building systems were increasingly developed, enabling time and cost savings, as elements were commonly mass produced for the construction of buildings in the housing, education, commercial and industrial sectors. The design of these structures was often subordinate to their production and construction principles, indicating a paradigm shift.

At the beginning of the 1960s, the different elements of large-scale projects often had to be prefabricated in field factories on or near the building site. In the ensuing years, however, an increasing number of independent prefabrication factories began to be built in all industrialised countries. The resulting reduction in the distances travelled to transport materials led to industrially mass-produced building elements being employed at a previously unprecedented scale. The subsequent development and application of different casting techniques, such as slip casting or lift slab constructions, were also significant, as they not only aided the advancement of the industrial prefabrication of elements for later assembly, but also the automation of the building process and the construction site itself.

The 1973 oil crisis, however, proved an impasse for these developments; the Organization of Arab Petroleum Exporting Countries (OAPEC) proclaimed an oil embargo on the US, disrupting the energy supply, triggering recession and unleashing the very real long-term possibility of high oil prices. This created a new awareness of the limits on economic growth, while population rates concurrently stagnated. By the mid-1970s, attempts to fully industrialise the building process declined or were abandoned in both Europe and the US. At the same time, the social problems of towns, which had been planned to be mono-functional, and their mass-housing estates became apparent, and the planning principles of the boom years, based on growth, progress, technology and prosperity, were mostly replaced by ecological strategies and economic considerations. In contrast, Asia did not experience the same dramatic turnaround. Its increasing population and growing cities, resulting from rural depopulation, continued to create demand for the construction of large buildings as well as large building masses. Simultaneously, the lack of skilled labour, especially in Japan, led to the promotion of automation in prefabrication and construction as an alternative to common construction practices.
Towards Automated Housing Prefabrication

Automation in housing construction started in Japan in the 1960s, with large prefabrication companies such as Sekisui House, Toyota Home and PanasonicHome, which were all descendants of firms that had already successfully employed automation in other sectors. Their manufacturing processes were characterised by a shift away from the construction site to a structured and automated factory-based work environment. In the case of Toyota, for example, 85 per cent of work was pre-executed off site. Nevertheless, the production process in these factories was, for the most part, still conducted by human labour, so it owed more to the organisation of the assembly line than to real automation.

In contrast to European approaches, where prefabrication was primarily optimised to achieve fast and cheap production of large numbers of identical elements, the major achievement of the Japanese prefabrication industry was their quite early success with customisation and personalisation, as well as their ensuing knowledge of users’ demands. The structured assembly-line work, combined with the advantages of human labour in a factory environment, allowed for the individual adaptation of single parts meeting customer demand without disturbing the production chain. They could simply be taken out of the assembly line and replaced manually, to be reworked or finished, before being introduced back into the next stage of the production process, causing minimal disruption to the overall productivity. This approach can be understood as a direct ideational precursor of today’s promotion of robotics in architecture – even if it was, of course, far from real automation and levels of productivity a modern industrial robot can achieve.

A common characteristic of the early manufacturing systems of the Asian housing prefabrication industry, which is quite distinct from conventional or traditional product production, was the focus on ongoing development. It was this that optimised them for automated manufacturing. Building systems and manufacturing technologies were mutually adapting to each other.

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Single-Task Construction Robots

In 1975, after the first experiments in the industrialised prefabrication of ‘system houses’ (consisting of various structural, exterior or interior wall subsystems etc) were conducted in larger series in Japan, and the first range of products, such as Sekisui M1, the first industrially mass-produced house type, achieved market success, the main building contractor, Shimizu Corporation, set up a research group for construction robots in Tokyo. The intensification of research in this field during the following decade was based on the 1970s ‘robot boom’ in the general manufacturing industry. The adoption of robots was thus a logical approach for Japanese construction firms.

The single-task construction robots that were subsequently developed were a distinct departure. Rather than merely shifting complexity from the construction site into a structured prefabrication environment, they deployed robotic systems locally on site for demolition, surveying, excavation, paving, tunnelling, concrete transportation and distribution, concrete-slab seeding and finishing, welding and positioning of structural steel members, fire-resistance and paint spraying, inspection and maintenance.9

The initial focus was on simple systems that could execute a single, specific construction task in a repetitive manner. Their steering was, in most cases, conducted manually, and was only rarely automated. Since upstream and downstream processes were also not usually integrated in these single-task construction robots, and safety measures were required because of the inferior parallel execution of human work tasks in their operation area, productivity gains were often counterbalanced. The evaluation of the first such robots therefore resulted in the conclusion that an off-site approach would be most suited to the organisation of on-site environments. Sites would be better structured and designed like factories, and the final goal was the implementation of automated manufacturing and construction technologies.10

Hence research in automated construction was intensified in Japan, leading to the development of so-called integrated automated construction sites.11
Implementation at a Larger Scale?
The historical development of the building industry shows that every innovation in construction technology needs at least one generation to establish itself, no matter how groundbreaking the first experiments or prototypes may have been. While early attempts by the building industry to use industrial materials and production methods were accepted bit by bit (with all their pros and cons) and subsequently changed the organisation of the construction site, the time has perhaps come for automation and robotics to establish themselves in architecture at a larger scale.

Advances in automated construction continue to be developed, especially in Japan and other Asian countries, and are slowly starting to consider the need for customisation of an increasingly individualising society, as well as of the intrinsic conditions of architecture. At the same time, the use of flexible industrial robots in the prefabrication of building elements, as well as in architectural research institutions, is becoming more widespread. However, instead of merely trying to copy and perform long-established construction technologies or prevailing factory automation methods, in order to achieve their inherent performance potential new robotic tools require appropriate conditions, design strategies, kinematics, programming and control. Strong complementarities exist between the actual building – its design, manufacturing and information technology – and its construction and organisation strategy. The next real change will only occur on the construction site once design, management and engineering comply with the robot as a new tool.

Integrated Automated Construction Sites
The first concepts for such structured environments for larger automated construction emerged from 1985 onwards, integrating the earlier single-task construction robots as well as other elementary control and steering technologies as subsystems. These integrated automated construction sites were organised as partly automated, vertically moving on-site factories providing a shelter for on-site assembly, which was controlled, structured and systemised, and unaffected by the weather, as well as for a disassembly process of prefabricated, modular low-, medium- and high-level detailed building components. Robot technology was thus facilitated by the creation of the right conditions to install automated overhead cranes, vision systems and other real-time control equipment.

The conceptual and technological reorientation from single-task construction robots towards integrated automated construction sites was instigated in 1982 by the Waseda Construction Robot Group (WASCOR), which brought together researchers from major Japanese construction and equipment firms in a single initiative. In total, about 30 sites were developed, some as prototypes and others as commercially applied systems. However, their market share and application was limited due to relatively high initial installation costs. These integrated automated sites and their subsystems, such as automated logistics, alignment, welding etc, were thus used mainly when the special conditions (land prices, high labour costs, traffic, noise and waste restrictions) of a project required them.

Since 2008, Japan’s major contractors have also developed mechanised and partly automated deconstruction systems, which generally follow the same approach as the automated construction sites, in reverse. The advantage of being able to reduce noise, dust and disturbance of the surrounding environment that these deconstruction systems afford strongly supports contractors’ new project acquisition strategies.

Obayashi Corporation, Integrated automated construction site concept, Osaka, Japan, 1985
Conceptual idea developed for Obayashi in the mid-1980s. The isometric drawing shows the concept of an upwards-moving factory on top of the building whose elements it is producing and assembling.
Notes

2. The Crystal Palace was originally built by Joseph Paxton in Hyde Park, London, for the Great Exhibition of 1851. In 1852, it was deconstructed, and it was rebuilt in Sydenham in 1854. Chup Friemert, Die Gläserne Arche: Kristallpalast London 1851 und 1854, Prestel-Verlag (Munich), 1984. For photographic documentation of the later building site at Sydenham see: Philip Henry Delamotte, Photographic Views of the Progress of the Crystal Palace, Sydenham (London), 1855.
4. Ernst Neufert, Bauordnungssätze, Verlag Volk und Reich (Berlin), 1943.
5. Originally cited in German in Günther Gottwald, Philipp Stein and Kurt Walz (eds), Neue Bauweisen: Bildfachbuch Nr 1, Rödelheim/Frankfurt am Main, 1951, p 3.
6. Interesting in this context is the psychoanalyst Alexander Mitscherlich's pamphlet Die Unwirtlichkeit unserer Städte: Anstiftung zum Unfrieden, Suhrkamp (Frankfurt am Main), 1965. Or the discussion about the Pruitt-Igoe urban housing estate in St Louis, Missouri (1954), the demolition of which was referred to as 'the day modern architecture died' in Charles Jencks, The Language of Postmodern Architecture, Rizzoli (New York), 1977, p 9.