

VERTICAL SHIPYARD: TECHNOLOGY TRANSFER FOR AUTOMATED CON- AND DECONSTRUCTION

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ABSTRACT: In this paper, we show that automated con -and deconstruction systems often are complex combinations of horizontal and vertical process, assembly and logistics sequences. The combinations of those horizontal and vertical sequences are exactly what characterize today's ship production. Shipyard technology is highly advanced and individual, customized ships are built with a high degree of automation. We outline that first attempts have been made by German architects and Japanese construction companies to utilize shipyards, shipyard processes and shipyard automation technology to construct buildings or building elements. Further, we suggest the utilization of South Korean shipyard technology (organization, logistics, processes and automation technology) to support and speed up South Korea's current R&D in automated building construction by proposing technology transfer from "chaebol" shipyard to construction industry.

Keywords: *Automated Construction, Shipyard Technology, Construction Management, Automation Technology*

1. INTRODUCTION

Automated Con-and Deconstruction is characterized by a high degree of integration of organization, logistics, processes and automation technology over the whole value chain. It follows basic principles in organizing processes: on-site automation is characterized by complex combinations of horizontal and vertical sequences. Two historical attempts which have explored these basic principles are presented in this chapter.

1.1 Location Orientation Manipulator (LOM)

1969 one of the first 7-DOF kinematic was designed by K. Wachsmann and his Team, John Bollinger and Xavier Mendoza. Except of some exhibitions within the seventies, in which this project was described shortly, the Motion Machine or Location Orientation Manipulator (LOM, **Fig. 01**) remained nearly thoroughly unknown. LOM is one of the very first Manipulators and should be a prototype for architectural assembly assignments and systems and, which should lead to further research on an empirical basement. Concerning construction assignments, K. Wachsmann and his Team realized the gap of the automated assembly systems as essential for the introduction of totally

industrialized and automated building systems. This approach is a sign of a highly valuable view of the interdependencies between the production and assembly systems and the building systems and concepts. This kind of holistic approach concerning the technical and technological needs and requirements of the construction, production and assembly systems is currently well known as Robot Oriented Design [1]. So, K. Wachsmann and his team took some basic developments of the following 40 years in advance, which makes it worth having a closer look at the project called LOM. [2]

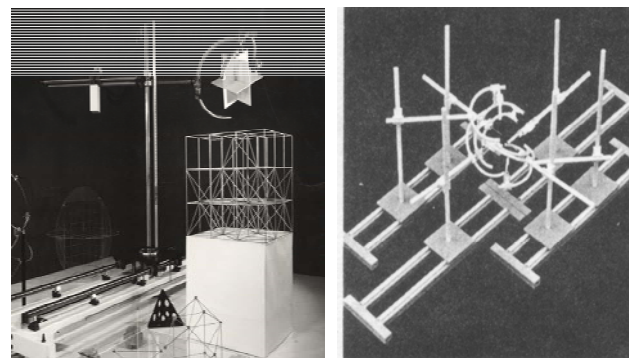


Fig. 01: A combination of several LOM units forms a complex central processing and assembly unit.

The kinematics of the LOM is modularized within a certain degree, so that it can be adjusted to various requirements, without the need to construct a totally new manipulator. Notably, a combination of several LOM units to form a complex central processing and assembly unit has been planned already, and was easily to realize, as the modularization of the manipulator has been considered since the very beginning of the studies. The physical independence of each unit allows arranging a number of LOM devices in different conjunctions.

1.2 Helix-Tower (HT)

K. Zuse (1910–1995) had many accomplishments on different fields of engineering. Early as 1957 he pointed out the need for automated construction. In the mid-1980s, he started thinking about the construction of buildings that could withstand strong storms and therefore could vary in its height. From 1989 onwards K. Zuse worked on the design of an auto-extendable and -retractable tower construction, the so-called Helix-Tower. The prototype was accomplished in 1993, had a scale of 1:30 and was named HT1 (**Fig. 2**). The Helix-Tower is an assembly of metal components. It works purely mechanically and fully automated. The shell segments are stored in radially positioned magazines. Construction and dismantlement through the same process run forward and in reverse. Further, the components can be mass-produced and are composed in modular fashion.



Fig. 02: HT1 scale model, retracted (left) and extended (right). K. Zuses first approach concerning the design of an auto-extendable and -retractable tower construction.

K. Zuse thought of three different applications for the extendable and retractable tower: The usage as a look-out, as a radio tower in areas threatened by hurricanes and as a mast for wind energy plants. Several contemporary witnesses claim that in the mid-90's some architects were interested in the Helix-Tower. In Berlin, they planned to build a tower with a restaurant on its top as a tourist attraction. Furthermore, the Fraunhofer-Association was pursuing a project related to the Helix-Tower. [3]

2. AUTOMATED BUILDING CONSTRUCTION SITES

Since 1988 major general contractors in Japan investigated the potential complementation of integrated robotic and automated building construction systems. Early prototypic trials (SMART) had been realized in the Shimizu Institute of Technology in Etchujima in 1990. The first automated building system of the “Helix-Tower-type” was the AMURAD system by Kajima Corporation in Nagoya in 1995. As K. Zuse envisioned in his Helix-Tower all interior finishing works could have been executed in a save and weatherproofed environment. Another verification of K. Zuse’s ideas of retract-ability of a tower construction is the first automated disassembly of two high rise buildings in down town Tokyo in 2008. Further in this chapter we show that besides vertical processes horizontally oriented building prefabrication on the production line has been deployed. Most automated or semi-automated construction sites today are complex combinations of horizontal and vertical task and logistics sequences.

2.1 J-Up System of Sekisui House

The J-Up-System, which was developed by Sekisui House, one of the big Japanese prefabrication companies, is the pre-stage to the later On-Site Automation (**Fig. 3**). The system illustrates the basic principles. Being used more than 3000 times J-Up was created to enable small companies with only a few employees to build a free standing 2-storey residence without needing crane and scaffold with only the assistance of a Toyota platform truck. Thereby hydraulic presses, which can be carried by two people, are positioned on concrete foundation in order to

push up the initially ground-built roof. Afterwards the exterior walls and bottom beams of the first storey are being positioned, adjusted, fixed and then pushed up. Now, one has only to incorporate the exterior walls of the ground storey and the interior fittings can begin dryly. Admittedly, this system is still working in a rather small scale and is not automated yet, but it already shows amazing parallels to the ways of construction Konrad Zuse was thinking of and to the later more detailed described automated building construction sites and here the systems of Kajima and Skanska in particular.



Fig. 3: J-Up System: Hydraulic presses push up the building floor by floor enabling efficient construction on the ground floor level. Sekisui House.

2.2 „Arrow-Up“-System of the Company Fujita

The principle of the Arrow-Up construction system is building a steel structure in a way that allows it to always be built on the ground floor (Fig. 4). Thereby the steel framework is built first, which is necessary for the foundation of the attachment of the pressing cylinder. Afterwards storey after storey is built with prefabricated and always uniform steel parts. The shown example involves a multistorey car park with a lift system, which was created for an apartment building. The advantages of the assembly on the ground are the increasing quality due to the improved working conditions as well as the simplified material transportation. For an economic usage, it was necessary to build more than 10 storeys.

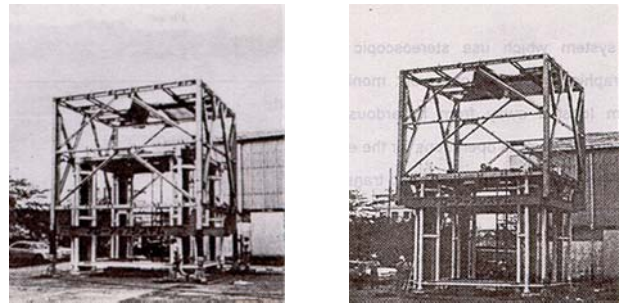


Fig. 4: Arrow-Up System states first trials of automating the self-climbing process of on-site construction factories.

2.3 Modular and Flexible On-site Automation

Since 1990, about 20 automated high-rise sites have been operated by various Japanese companies (Taisei, Takenaka, Kajima, Shimizu, Maeda, Kumagai, Ohbayashi). An automated high-rise construction site can be defined as a vertically moving factory (Fig. 5), combining semi- and fully automated storage systems with transport and assembly equipment (Fig. 5) and/ or robots to erect a building almost completely automatically. A further goal of those systems is to improve the organization of construction processes and construction management by using real-time ICT and advanced control systems, enabling a continuous flow of information from planning and designing in order to control the automated on-site systems. Today semi-automated high-rise construction systems are capable of creating individual and non-rectangular buildings. The high rate of defined processes reduces material, resource consumption and construction waste is nearly completely avoided. Moreover, on-site factories provide an appropriate and safely working environment. Automated Building Construction Systems can be designed highly modular and flexible.



Fig. 5: Super Construction Factory of Automated Building Construction System (ABCS, Obayashi). Z-Carry, Robotic Sub-system of an Automated On-site Building Production with AMURAD System, Kajima, Japan.

2.4 The AMURAD- System

The Amurad-system (Fig. 6), developed by the Kajima concern, is a way of construction, which is based on a new idea of beginning with the top floor, contrary to conventional methods and other automated building sites. Thereby the whole first floor, which is the top floor, is, after its assembly, pushed up one floor with the aid of huge hydraulic cylinders. After pushing up the storey, the plumbing work, interior fittings and the cladding of the facade begin. By repeating this process the building seems to pop up like a mushroom. For realizing the AMURAD-System the three following mechanical systems were developed: A system for floor-wise up-pushing of the whole building, the so-called (Z-UP). A transportation- and assembly-system (Z-HAND), and a material transportation system (Z-CARRY).



Fig. 6: The AMURAD Construction Strategy: for floor-wise up-pushing of the whole building. Kajima, Japan.

2.5 Skanska Method

Skanska has developed a method for automated construction of condominiums which from the basic principle shows many similarities to the AMURAD-Method: each floor's bearing parts are assembled by a robot system running on tracks in the ground floor and then the ground floor is pushed up. In contrast to AMURAD only one track is installed (Fig.7) and the construction is not based on columns but on prefabricated concrete walls that are positioned by the robot system.

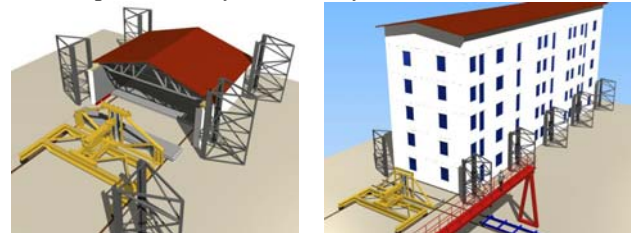


Fig. 7: Simulation and Pilot Test of new automated construction method: An automated system assembles the floors in the ground floor level. Hydraulic presses raise floors and buildings step by step. Skanska, Sweden, 2009.

2.6 Systemized Deconstruction

Within 11 months, three high-rise buildings in the center of Tokyo recently were deconstructed by a semi-automated

deconstruction system (DARUMA, Kajima, **Fig. 8**) Construction starts with the dismantling of the ground floor. While the dismantling of the ground floor took place, the upper part of the building was held by IT-coordinated hydraulics. With this method, floor by floor was dropped down subsequently and disassembled at the ground floor level. 93 % of the building components could be recycled (recycling rate of conventional demolition: 55 %).



Fig. 8: Systemic and automated Building Deconstruction allows for enhanced recycling and reuse rates (Urban Mining), Kajima, DARUMA System, Japan.

2.7 Customization and Re-Customization in Horizontal Building Prefabrication

In Japan customized fabrication has a long history. After the second world war Toyota Motor Corporation searched for a way to improve its' productivity by a factor of ten. Later the Toyota Production System introduced demand oriented production flow and revolutionized production thinking around the world. Toyota Home and Sekisui Heim have adopted and transferred these principles of horizontal production flow into building prefabrication. Today the Japanese prefabrication industry is prefabrication more than 150.000 buildings highly automated in factories and on conveyor belts. Today Sekisui Heim (**Fig. 9**) even offers remanufacturing and re-customization of its units and buildings.



Fig. 9: Customization and/or Re-Customization of Building units on the production line, Sekisui Heim, Japan.

3. UTILIZING SHIPYARDS FOR ADVANCED BUILDING CONSTRUCTION

Ships have many similarities with buildings: size, structure, materials used, providing shelter, etc. and huge ships are even organized similar as whole (swimming) cities. As we will show in this chapter also concerning the production processes and production technologies strong similarities can be identified. These similarities today can be used to transfer processes and technologies from highly advanced ship building industry into construction industry.

3.1 Bauschiff Neufert (German Bauhaus)

The idea of using technological elements of ship construction being highly systemic and rationalized is not new. Already E. Neufert in the first half of the last century developed a system to construct condominium buildings in a similar way as ships (**Fig. 10**). An on-site factory covered the assembly area and could move horizontally from building section to building section. Within this factory, the building components were assembled in a vertical process.

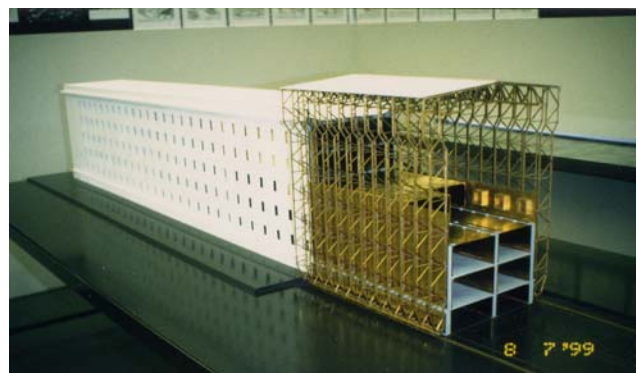


Fig. 10: Neufert Bauschiff, Bauhaus, Weimar.

E. Neufert was one of the first Students of the Bauhaus in Weimar, and he was under the supervision of Walter Gropius dedicated to translate Henry Ford's ideas into architecture and construction. E. Neufert himself became famous for developing building standards.

3.2 ERP and Automation Technology

Due to advanced ERP and automation technology, individual and customized ships are built today with a high degree of automation. Logimatics's MARS System is a good reference for advanced shipyard technology. Logimatic has developed MARS, a vertical ERP solution for shipyards (Fig. 11). MARS was derived from horizontal production streams and adjusted to the specific needs of ship production implicating vertical processes. Due to its modular architecture, the functions of the system can gradually be upgraded from modules supporting pre-calculation and budget control up to plug-ins for waste handling and life-time-services. A major advantage of the MARS ERP solution is that it can integrate existing solutions into enterprises as for example existing planning or logistics systems.



Fig. 11: Advanced Shipyard Technology supports the whole shipbuilding process from purchase to assembly and maintenance. Logimatic, MARS

Main components of shipyard solutions today are:

- **Planning Modules:** Cost Control, Design Systems, Engineering Tool
- **Logistic Modules:** Purchasing, Resource Planning, Outfitting, Warehousing

- **Production Modules:** Steel Production, Prefabrication, Production Control
- **Maintenance Modules:** Maintenance, Waste-Handling, Life-Cycle Management

The combination of systemized, modular construction, ERP solutions and the use of advanced automation and robotics have reduced production costs and provide high earnings for shipyards around the world.

3.3 Utilizing Shipyards for Construction

The Yokohama International Passenger Terminal (Architects: A. Zaera-Polo, F. Moussavi) had been constructed by Shimizu [4] using a shipyard to build the complex segments of the building. The total floor area of the building is 34,699 m² distributed over three stories. Fig. 12 Shows how the building was systemized and finally split in segments and elements. Fig. 12 also shows the highly automated production of the components and the assembly of those components into the above mentioned segments.

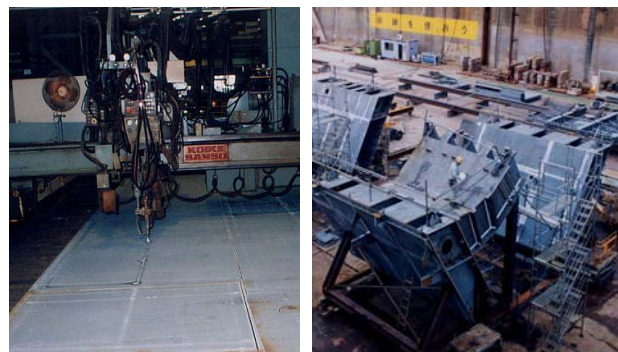
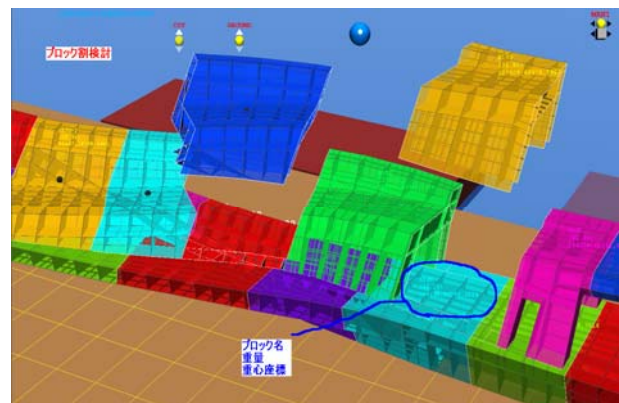


Fig. 12: Production of main elements of the Yokohama International Station in a Japanese Shipyard through Shimizu.

3.3 Korean “Chaebol” Structure

Due to industrial “chaebol” structure in Korea it is even easier in Korea to transfer shipyard technology “inhouse” to construction industry. Many Korean companies have multiple business fields as for example Samsung which is active not only in shipbuilding and construction but also in the automotive sector, electronics and the steel industry. In contrast to many other countries around the world, Korea up to today managed to keep this structure of its industry. Now it could use it to gain competitive advantage in the construction sector.

CONCLUSION

In this paper, we have shown that automated construction and deconstruction systems often are complex combinations of horizontal and vertical task and logistics sequences. Some approaches focus more on the horizontal processing (e.g. Helix-Tower, AMURD, DARUMA), others on vertical processing (Sekisui Heim, Toyota Home, Skanska). Yet, basically automated on-site construction always implies horizontal (e.g. component delivery, etc.) and vertical processes, which need to be addressed by the systems organizational and physical structure. In chapter 3 we have shown, that the combination of horizontal and vertical process streams needed for automated construction and deconstruction are exactly what characterize today’s ship production. Shipyard technology today is highly advanced and individual, customized ships are built with a high degree of automation. We have also shown that already first successful attempts have been made by German architects and Japanese construction companies to utilize Shipyards, their processes and their automation technology to construct buildings or building elements. In further research, we want to explore the potential of utilizing South Korean shipyard technology – Korean shipyards are accounted to be among the world’s most advanced shipyards - to support and speed up South Korea’s current R&D in automated building construction by technology transfer within Korean “chaebol” structure.

REFERENCES

- [1] Bock, T., Robot Oriented Design, Shokokusha, Tokio, 1988
- [2] Bock, T., Lauer, W. “Location Orientation Manipulator by Konrad Wachsmann, John Bollinger and Xavier Mendoza”. 27th International Symposium on Automation and Robotics in Construction (ISARC), Bratislava, 2010
- [3] Bock, T; Eibisch, N. “The Helix-Tower by Konrad Zuse: Automated Construction and Deconstruction”. 27th International Symposium on Automation and Robotics in Construction (ISARC), Bratislava, 2010
- [4] Dr. Yusuke Yamazaki, Vice-Director Shimizu Institute of Technology
- [5] Bock, T., Linner, T., Lee, S. “Integrated Industrialization Approach for lean Off-/On-site Building Production and Resource Circulation”. 7th World Conference on Sustainable Manufacturing, India, 2009
- [6] Logimatic, MARS vertical ERP solution for shipyards, Website: www.logimatic.com, last visited: 12.03.2011
- [7] Master Course “Advanced Construction and Building Technology”, www.br2.ar.tum.de - T. Bock, T. Linner