CONCEPT OF BUILDING SYSTEM FOR ROBOTIZATION
A SYSTEMATIC APPROACH FOR DEVELOPMENT AND DESIGN

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INTRODUCTION

Industrialization can be considered as a process which is not yet finished. This process started at the beginning of the 19th centrury in Great Britain. Historically the industrial revolution is one of many technological revolutions and processes of civilization forming the evolution of mankind. Basically there are 3 revolutions:

- the agricultural revolution where man began to cultivate food and keep animals thus becoming producer of food
- the urban revolution where handcrafts were developped
- the industrial revolution where mechanical energy was utilized.

The productivity of human work was multiplied by an increasing number of mechanical developments; farmers and craftsmen became factory workers, the manual production gradually decreases and factory-based production starts. Recent introduction of nuclear technology, electronics, biotechnology and computer integrated manufacturing systems might still be considered as part of industrial revolution or as a new revolution whatever is appropriate.

FUNCTIONS OF MANUFACTURING

The development of tools can be seen in the industrialized production where the manufacturing system becomes more or less independant from power and skill of craftsmen.

The machine-oriented production process can roughly be subdivided into 4 functional levels:

1. Function of power generation
2. Function of forming
3. Function of controlling
4. Integration of all above mentioned 3 functions.

The function of power generation was replaced by e.g. steam engins and skillful labors were replaced by tool machines which can be seen at the example of window element production where automation is very advanced. The control function such as measuring is replaced by computers. The machine can produce constant quality parts which can not be made by human hand. Flexible automation and CIM can be considered as the highest level of industrialization. The product being produced through a system of machines which is able to adapt various kinds of changes without human interfering. The functions of power generating, forming and controlling are executed by a system of interacting machines.

SITUATION OF AUTOMATION IN CONSTRUCTION

In many industries automation is very advanced. Functions of human labor are gradually replaced by machines. But as far as building industry is concerned, automation is not yet commonplace in all stages of manufacturing. The industrial building production is most advanced at the product level of materials and parts production, such as steel sections, cement and glass. (table 1

Human labor is only partially substituted by machines at the product level of building parts and groups. The productional functions of power generating and manufacturing are mostly replaced by machines except the controlling functions. Automation is least advanced especially at the final stages of production hierarchy, for example the manufacturing of building kits and the final assembly. The human labor at on-site construction is only substituted for its power generating functions such as cranes. The functions of human labor requiring skill such as forming, adjusting and assembling are carried out and controlled by workers. Besides the fact of low productivity, aging workforce, lack of skilled workers and poor quality are also the death/accident rate and occupational disease of bilding industry is higher than that of other industries. Among the bilding industry, the prefab makers showed lowest rates except for on-site operation.(1

STATE OF THE ART OF PREFABRICATION IN CONSTRUCTION

Industrialization is more advanced in the prefabrication due to clearly defined circumstances at the place of production, similar to applications of industrial robots in other manufacturing industries. In Japan and other industrialized countries the modular house industry reached a high standard of production technology through mass production of limited variety of un-differentiated building elements, components and units.

For example at the production line of Sekisui Chemical-Sekisui Heim, for box units where more than 85% of the house is prefabricated, quality control became as thorough as for other industrial products. The steel frames of the unit are assembled from the roof-, floor-, and end wall frames which are welded together in a totally automated process using arc- and spot welders. Production process starts with cutting of prescribed length of highly rust resistant fused galvanized steel. Robots then weld connecting fittings to the columns. At the ceiling frame production line, 2" x 4" beams are attached to ceiling frame and electric wiring is installed. In the floorframe production line, insulation is laid on the floorframe and an automatic nailer installs the floor boards. Another automated process assembles columns fitted with connecting lugs to form a column frame. The frames are spot welded together in a fully automated process. The frame supports serve as jigs establishing the frame's dimensions. After the exterior wall panels that are manufactured on a subline, are fitted to the structure, the interior items and partitioning panels are installed. (2

COMPLEXITY OF CONSTRUCTION

Industrialization of building production advances gradually from material and parts production to building parts and partially building groups. Future efforts should focus on the total industrialization of construction. Therefore it is necessary for the building industry to increase R&D expenditures especially on the development of a software of building system. More than other industries the construction industry is highly fragmented into 62 different skillful occupational categories. (3 A machine that would execute these skillful works would be very expensive. Therefor it seems to be appropriate to develop a buidling system which is enhancing the use of robotic technology. Elements of this new system have to be designed for robot-oriented processes.

In order to systematically develop the robotization in building industry, a cybernetic appraoch is helpful. Building industry can be considered as a total interactive system of production planning, production, products and marketing. In the history of industrialization of building construction, the material part of building system was more emphasized than the software part. The result of this development can be seen today in mass produced apartment blocks and marketed prefabs.

TOTAL BUILDING MARKET

An intergrated software and hardware system is required for promotion of robotics in construction. This software system consists of parameters of all subsystems of building system. These parameters contain data of any stage of developmwnt, planning, production and organization. Through implementation of this total system, the existing building market will be reorganized. Ideally this new market should resemble some how the car market where a client can purchase a car from any maker. Therefore all specifications have to be standardized. Hierarchcal structure of organization, production, and planning should be proposed and elements of this structure have to defined and coordinated among each other. Productivity of building can be increased through decrease of time elapsing between start of planning and start of utilization of product(=house). (4

Decisive for the required planning and construction time is the fact how many partial planning and production processes are already completed at the time of order entry. Some operations of planning and production should be programmed or prefabricated. This is easier to achieve when there is steady demand. Also operations of planning and production are executed not for contract-oriented. (table 2

INCREASING PRODUCTIVITY AND FLEXIBILITY

To attain homogenuous and continuous production, the producer can setup catalogs of specifications. This procedure can be realized through definition of the development and design of building system.(5 Products which are produced under noncontract-oriented conditions can be changed if these changes have been already programmed. In case of unexpected changes, more time is required due to testing, feedback and correction. This is also a part of innovation since solution of unexpected changes contributes to product development through improuvment of productivity, quality and prize.

Homogenuous and continuous production can be also furthermore attained through design of building system and it's subsystems for a wide range of application. To accomplish greater flexibility of planning, a standardized building system is required.

In order to react to changing demand while maintaining homogenuous and continuous production, some rules of planning have to be defined which become basis of communication for planner and producer. The standardization as we can see in present building industry, failed to generate continuous sales. Building elements increased in size and became function-oriented, consequently reducing variety and possible applications range.

The required standardization for robotization of construction should increase productivity and flexibility of planning through highly differentiated production of components and integrated control of operations.

STANDARDIZATION OF BUILDING SYSTEM AND DATA

Building components have to be standardized to enable automated production and assembly for various combinatons of elements of building kit. Hence a modular coordination of elements of all subsystems is required. Generally acquisition and processing of catalog and project data is desired. This includes providing of following information functions:

- machine-oriented data such as downtimes and production times
- system-oriented data such as overall downtimes production time, failure time, utilization capacity

- project-oriented data such as scheduling, actual vs estimated times, current status
- planning-oriented data such as eventual information for planned project contruction

Building components are specified to comply with various physical and geometical requirements. Whether the system is open or closed is just a matter of the range of application of standards. The building system should adjust to quality/quantity changes in demands and technology.

CATALOG DESIGN SYSTEM

The basic software system consists of series of catalogs containing requirements and operations of each level of manufacturing, specifications of functions and geometry of all subsystems, procedures are necessary for the assembly of desired functional and structural untis. The catalogs are structuarlly organized and elements are defined, according to their manufacturing level in the building system. The clearer the manufacturing hierarchy is defined the easier robotics can be implemented.

Further catalogs of building system contain information of methods, regulations, rules and operation, structural and functional solutions, interface rules for coordination of elements. (6 Datas on physical and geometrical specifications reflect hierarchy building system. Functional datas are required at all levels of project describing categories of functions. (table 3

The functional and structural qualities of building components of all levels should be described in such a standardized catalog including a method to integrate specifications between all levels of production.

Production related specifications are described as:

- manufacturing processes
- handling operations
- manipulating operations
- robotic operations
- and coordinations of above mentioned. (table 4

Another catalog consists of rules for the coordination of building components where the geometrical system is described how to coordinate components of any functional quality at any level of manufacturing. Besides the geometrical order of elements, there is the geometrical order system of tolerances which is required due to varying accuracies. This tolerance coordination system is very important because it is also contents the interface of machine and work piece of components. This furthermore contributes to conflict-avoiding assembly by robots. (7

Another catalog contains methos for structural development procedure. For the construction process, the geometrical physical data of building components have to be coordinated with the manufacturing operations. All elements of building system and operations are composed of datas from the various catalogs which can be easily compaired to other solutions.

METHOD TO DESIGN JOINING SYSTEM FOR ASSEMBLY

A systematic design process will be shown at the example of conceptual development of a joining system, in this case of elements of structural wall system. The concept of joining system is decided by type, way, manner of forces and moments transmitted, the motion during assembly and adjusting, environmental conditions, assembly-, transportation-, and production oriented requirements.

Similar to the hierachy of the building system, a joining system can be also structured into joining group, -parts and materials. (table 5 Also the specification of joining system can be described geometrically, physically and functinally in the catalogs. It is suggested that the design procedures follow the recomendations of VDI 2222.[8]

First the requirements and functions of joining system have to be defined and then their compatability with specifications in the catalogs can be checked. A joining system consists of one or more joining groups and their compliance with appropriate joining groups of the catalog has to be checked. The combination of joining elements to groups can only be realized through consideration of relations of elements among each other. Therefore a planning program indicates the process of developping the structural solution. Planning procedures such as:[9]

- coordination of functions
- coordination of building subsystems
- production-oriented, transportation-oriented and assembly-oriented restrictions influence the design

In the future research a method to design and develop a structural system for joining two elements by a robot, will be proposed. The work will focus on the joining of lightweight prefabricated wall elements. Therefore it is supposed that ideally identical elements of a building kit are used that can be assembled in different ways. Furthermore joints and joining areas have to be identical to ease automatic assembly.

For example the brick is well suited for automatic assembly. And automated assembly machines for brick walls have already been developped to compose walls in different types and sizes.[10] Bricks are also ideal for mass production.

Any new system therefore has to an elementarized building kit sysytem.

CHARACTERISTICS OF ROBOT-ORIENTED BUILDING SYSTEM

A robot oriented building system should produce differnt buildings through components of kits assembled to various combinations with the help of a building program. As for most existing building systems, there is always the paradoxical requirements:

- inorder to comply accurately with the function of building and adapt to any form of design, the elements should be of small sizes and highly differentiated
- on the other side production-economical oriented reqirements ask for elements of larger dimensions and less variances.

An optimization between standardization towards fewer elements and variation towards highly differentiated elements has to be found.

Finally it can be concluded that a robot oriented building system requires following:

- interface of building parts have to be coordinated and standardized to enable interchange ability
- the system is characterized by program which can show possible patterns and combinations
- the system should be serviceable, i.e. building elements can be used in different ways
- application range of building system has to be defined
- accuracies of work pieses, tools and machines have to be coordinated
- work pieces and machines should be lightweight
- geometrical and physical qualities have to be defined

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New Version

Industrialization of building industry is gradually substituing functions of human labor by advancing production technology.

Automation of construction progressed considerably in the prefab industry and especially in modular house production. Existing structure of building industry and market does not support further wide-spread use of robots.

A systematic approach to develop and design a concept building system for robotization is proposed. Exact definition of manufacturing hierarchy is needed to clarify functions of various subsystem of building system.

An integrated concept of robot-oriented design and development of building system is proposed through help different catalogs describing:

- Geometrical and physical qualities of elements

- Functional and structural description of subsystems

- Coordination of all elements through tolerance system and interface rules

- Classification of building system

- Product levels and related machine categories

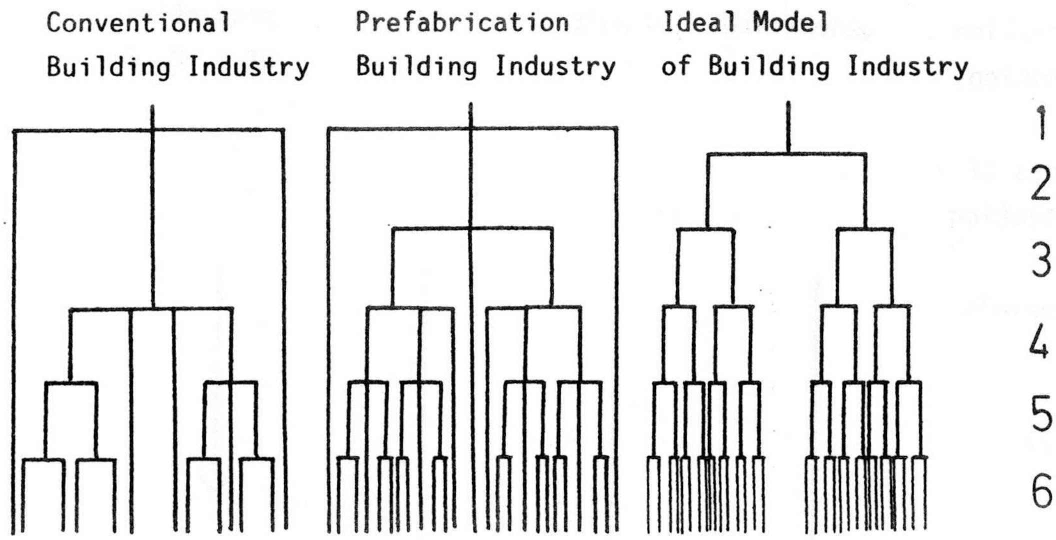
Table 1

Substitution of human work at various stages of production

	1	2	3	4
Functions of production technology	Power generating	Forming Manufc.	Controlling	Integrated production of 1, 2, 3
Stages of production				
Materials	↓	↓	↓	↓
Parts	↓	↓	↓	↓
Building Parts	↓	↓	↓	
Building groups	↓	↓		
Building kits	↓			
Final product	↓			

Table 2

Manufacturing hierarchy for diffent degrees of industrialization



1 = Final Product (House, Building)

2 = Building Kit (Interchangeable standardized elements)

3 = Building Group (Complex Components such as Box Unit)

4 = Building Part (Wall elements, Window elements)

5 = Part (Precut Wood)

6 = Material (Steel, Cement)

TABLE 3

Product Structure	Manufacturing Hierarchy	Machine Categories
Group of 1st Order	Final Product House	Machine CAT-1 e.g. Mobile Machines
" 2nd Order	Building Kit	Machine CAT-2 e.g. Mobile/Fixed Machine
" 3rd Order	Building Group	Machine CAT-3 e.g. Box Unit Production Machines(IR)
" 4th Order	Building Part	Machine CAT-4 e.g. Window Production CNC Machines
" 5th Order	Part	Machine CAT-5 e.g. Precut Factory CN Machines
" 6th Order	Material	Machine CAT-6 e.g. Manupilator Steel Factory

Table 4

Machine Category I (Mobile)

- (1) Manipulator
- (2) Handling System
- (3) Robot
- (4) Combination of (1), (2), (3)

Table 5

Joining system hierarcy for structural, functional, geometrical and physical qualities.