

Innovative and Intelligent Parts-oriented Construction (IF7-)

Summary Edition

1. Project Purpose and Goal

It can be said in general that the construction industry is, regardless of its nations it belongs to, advanced or otherwise, of local character bounded to the narrower view on its marketplace, supply chain, and technology advancement. So fragmented are they, albeit of its huge market-size and opportunities, that it has been, in the aspects listed above, far behind the manufacturing industry like the automobile, aerospace, and many other manufacturers, lest to mention the IT industry. The partners in EU signaled to us a major new initiative, aimed for breaking this socio-economical stillness and prejudice, stepping forwards to create a new industrial formation worldwide at the dawn of the new-born century. It was the thematic network thus proposed as is commercially oriented that provides with a mechanism for this adventure entitled “Manufacturers of Housing”. It is the act-of-potency in this domain, we all realized, that leads us to further advancement in incorporation of the manufacturing mechanism in our industry. Along with this line, the first phase of the IF7 project was commenced jointly with our partners in Europe. The project of phase 2 was further advanced to a fundamental change of paradigm.

We all notice that the Internet has driven forcefully the way we do business and will continue to do so in the coming decades. It is the information network that has changed the surface of the globe permanently so that nobody can dream up even reversing it. However, what is flowing in the business of manufacturers and construction alike is not merely information, but more importantly the material flow. The supply chain network is indeed the primary concern of our time that needs some paradigm shift as the Internet brought about for information. If there is a way where the information packets and material parts go around in hand with hand over the net, the information network and its material counterpart will be no longer considered distinguishable. If every one of the parts for assembly has a chip with antenna implanted which contains a unique address “Product URL”, it alone opens up a new horizon over which the two networks work together synchronically. The idea along this line is already intensively being studied by several eminent research organizations over the world. It is as simple as the Internet, and yet it reaches the scope as wide and as deep as the Internet.

Coming around the corner is the technology that brings about another major impact on our way of business to the comparable degree as the Internet did. Given the

technology we are most likely to be forced to restructure our product model of buildings, process model of construction, data model, construction management and the supply chain model, in short, overall business model for our construction industry. It will above all provide us with chance and opportunities to be able to solve the long-standing problems that have confronted us so long – implementation of manufacturing mechanism in construction.

Of course even one large project cannot solve all the problems related to implementation of manufacturing mechanism in construction. We thus proposed and created an International Platform of IT based Reformation in Construction under the banner of “Product URL –addressed Parts Oriented Construction”. For the purpose to clarify and extend its unique characteristics further, here we describe some of many possible applications at construction sites, not to restrict its much broader scope.

(1) *Quality Engineering*

Construction parts (building materials, components and parts) and design information are currently supplied to the construction workers separately. The skilled workers then interpret the drawings to map its graphic information to the construction parts available at hand. The current practice thus heavily relies on the interpret skill of the workers, that induce uncontrollable randomness in quality achievement. If each part carries the relevant design information or can access to the remote servers swiftly via its address, the workers can retrieve only the relevant procedures necessary for its implementation. So that way an even unskilled worker can achieve the precision comparable to the manufacturing workers.

(2) *Life-cycle Engineering*

2 –3 million parts needed for a building, depending on how to count, and yet the vast bulk of construction parts can easily be registered in and retrieved from D/B by this system. We thus can keep all the information of parts and their history in log. 80 –90 per cent of the life cycle engineering can be solved by this bulk of D/B. Parts comparability with this parts-level information retrieval will make possible replacement of parts in a building to its full extent, even perhaps structural modules, not to mention the infill. It will eventually erase the current dichotomy between renovation and newly-build in its entirety.

(3) *Supply Chain Engineering*

One can easily see the impact on the supply chain is far vast than ever achieved, for parts and packets (i.e. material and information) are no longer separable.

(4) *Construction Management*

This IT-based Parts Oriented Construction will allow the Cost Management to achieve its full transparency due to its accessibility to the parts-level information. For the design and execution are far more closely linked than ever achieved, controllability in Construction Management will increase drastically in result.

(5) *Inverse Manufacturing*

The Inverse Manufacturing is reverse processing from the artifacts to their components for the purpose of recycle and reuse. It moreover represents creation of a new industry to close the loop of industrial activities from the sold artifacts to the re-fabricated artifacts by reuse. The implementation of the Inverse Manufacturing however presumes the accessibility to the parts-level information of their material characteristics for recycle and reuse.

(6) *Standardization of Product Model, Process Model, and Parts Specification*

Though standardization of product model and process model is moving forward elsewhere, it is necessary to accelerate it and to incorporate parts oriented view. The IT-based Parts Oriented Construction and standardization activities of modeling will promote each other and provide each with solid basis. Standardization of parts specification will make it possible that parts can go around freely over the net and across the borders.

Though only a few of the possible applications were listed above, one may be able to see already the vast scope of its impact, only comparable to the Internet revolution. It is not a mere replacement of the existing technology by a new one, but a paradigm change, that requires or induces the industrial rearrangement across the world. This depth it can reach to and this scope it can span over requires the International Collaboration Program IMS.

2. Part of the interior

2.1. First of all

Various trials have been conducted in order to realize "the manufacturing industrialization" of the job site. However, it is difficult to introduce the production system by controlled environment, like in factory production, into the job site. To say nothing of disturbance factors, such as the weather and local environment, the main factor is in the place that cannot apply the model "the controlled production environment" according to the diverseness of the work occupational description in the job site, and the various complication factors accompanying it. Since building-materials manufacture needs to adapt an asymmetrical production system like production in the factory and installation at the job site, a problem will become more complicated.

In order to cope with such a problem, it is necessary to introduce a control mechanism application which can be adapted equally to the asymmetrical production style of a factory and the job site. The main subject is concerned with performance for the gate management of parts and packets unification in order to use one apparatus required for mounting of the control mechanism. This will make the kernel the active database that sends a message, automatically changing the data.

2.2. Mechanism of the change

The construction parts are not only a design stage, but in constructing a job site changed frequently. In this case, if an easy concept may also become a big change several days after a change of the Building material is made on a drawing and it is told to it to a manufacture figure design and manufacture, after change takes place, it will also take several weeks. It is the present condition for a manufacture figure design and manufacture to advance with the drawing before the change, and to also generate excessive cost in the meantime. It becomes an important element to carry out, after the change takes place, that the proposer understands "the expense" and "the influence on the time necessary for completion", in order to suppress generating of this expense. And in order to grasp the influence that affects each work process simultaneously with change generating, it becomes necessary to share this change generating information.

It is an "information shared" duty to reduce a time loss, and the manufacture concerned becomes what change transfer into other finish material manufacture who are obliged to change with "shares information for simultaneously". Although it is a subject to make the structure of generating this information share and a transfer event, it becomes an important point then, to build the structure which took into consideration not the relation of "one to one" centering on a General Constructor, but the relation between "one to many" and "many to many" in the job site.

Especially, from drawing recognition to the shipment are only a maker's processes, and the progress cannot be read at the job site in the present condition.

However, a change during this period is the big point of "cost generating", and it also becomes possible to prevent cost generating by understanding which position the Building Material is now. If you can detect the cost generating point, you can produce the big possibility by sharing the information through which gate the Building Material passed is now. When the information is entered by reading the present situation of the Construction Material, which is a parts and packets unified object through a server at each gate, the act of reading and writing serves as a trigger, an active database starts, and the production situation of the whole which changes every moment is controlled. According to the gate management, the asymmetrical production style of factory production and the job site is carried out generating an event in the core, dynamically combined through a parts and packets unified production system.

2.3. The gate management

A building-materials manufacture's main process serves as a "processing and assembly", "shipment", "delivery", "distribute a product at job", "installation", "inspection" and "receiving". This seven process becomes a management gate as a point of changing the environment on the schedule. The construction parts ID and each material parts are related to make a tree system to cope with the change.

The construction ID is given as "AW/1 (201)" for the aluminum sash of the specification of construction mark AW / 1, and it is used for Room No. 201. The details are shown in figure 2.1. The component (physics) ID level is consisted of the six material from "aa1" to "zz1" is shown structurally on the figure. The process is constructed as one part of a building (install to a building), and the construction process is expressed. When the process go through at each gate, the different colors, are distributed at seven gates, are changed such as processing and assembly gate is red, shipment is orange, delivery is yellow, distribution is green, installation is light blue, inspection is blue and receiving is dark blue. It is at the passage time and makes for a color to change into the promise thing on employment.

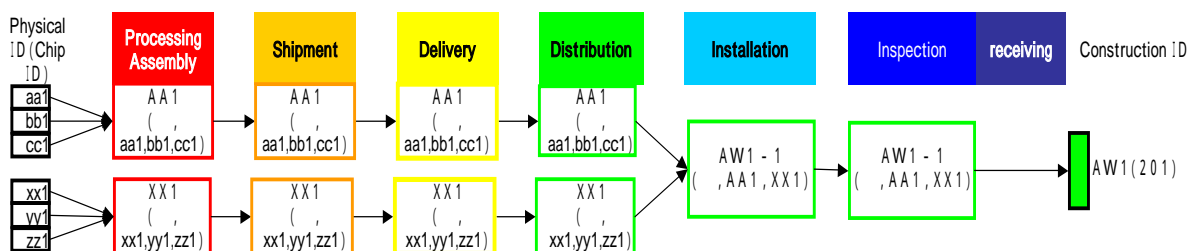


Figure 2.1 The establishment of gate

As a plan stage, by carrying out ID management of such a tree structure, the construction schedule of all processes can be share. For example, if the mark of a construction ID portion is "green" means the state of distribution is completed, and "white" means the state that has not been generated as a component yet, and a problem can be immediately discovered now.

2.3.1. Connect with Active database

ADB is the controller system, which makes a trigger event, such as rewriting to the contents accumulated to the database, and carries out "inducing the function of an event actively to the associated agent." This ADB is utilized and the process of a master schedule and each Building Department article (ID) are registered as a database. Each manufactures are set up so that the change information on the related parts ID may be received as an agent to ADB. (This is structure of "Glue logic" which carries out setting release of the condition setup of an agent freely to ADB.) By practical use of this structure, work is managed according to the state (a position and form) of the Building Department article (condition setup). As for this, not only exchange of the component in a production line but also recombination of the attachment process in the construction spot is included. The suitable process to which recombination was carried out from ADB though change arose at the process which a trouble occurs and follows at a certain process is shown.

2.3.2. ID management

A component is equipped with RFID in a certain stage, which the cutting material is finished, where ID management is needed. Then, the parts and ID's are unitized at the time. If the double sliding window is taken for an example, the sash consists of the "frame" and the "window" and the frame is made of four vertical and horizontal components. Moreover, the window have a component as same as the frame. Here, suppose that it equipped with RFID, which has ID "aaaaa" in one cut form material as component of an upper frame. This ID is the aluminum sash marked on a database with the construction mark "AW/1" used in the construction site.

aaaaa	A W / 1	upper frame
bbbbb	A W / 1	bottom frame
ccccc	A W / 1	vertical frame
ddddd	A W / 1	vertical frame
eeeee	A W / 1	flashing
fffff	A W / 1	window board
ggggg	A W / 1	...

Figure 2.2 the part of ID management

Also, this ID relate to the information, which there are 15 of the same aluminum sash in

the job site, and deliver to the job site on October 5. Also, ID “bbbbbb” has the information as well as “aaaaa” in one cut form material as component of a bottom frame. The important thing is that even if the aluminum sash is expressed with the several ID from "aaaaa" to "ddddd", etc., when we detects which ID by it, it shows the composition material of "AW/1."

2.3.3. Sharing the manufacture process information

The manufacture information is an ADB system's being interlocked with and performing schedule management on a job site. This situation will reduce a check in the job site and a chance to go to the job site. It can perform big improvement in efficiency. Using RFID to stuck on the material, the day, which if a big problem occur, it will be taken several weeks to solve the problem, will be reduced. The systems can send the information of changing situation at real time to the relational section, a quick response get to cope with the problem. By this system, RFID united with the material in the information of "gate passage" is read with an antenna, and by transmitting the contents which accompany the ID to ADB, where the material is located and it is notified to the manufacture (agent) related with state change through ADB. It not only can perform gate management, but by using the general communication equipment, it can share the situation of the job site simultaneously at an office, the job site, a factory, etc., and work directions, discover the problem, examination of the correspondence method, etc. can be performed smoothly. Also, using the Key Plan drawing to relate the ID information at each marks, the mark show the color of the gate when the material go through each sections.

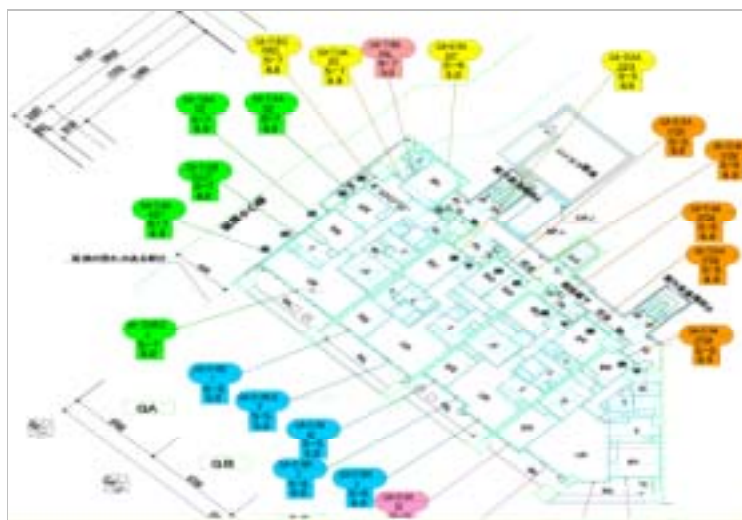


Figure 2.3 Sharing the manufacture process information

This system is called Active Process Control. If the change of specification and dimension are discovered at the process, the mark on the drawing will go on and off to show something

wrong as a notice. If the mark is clicked on the computer, the relational information will be appeared on the screen to indicate what kind of situation is happening. In order that such an unusual state and trouble correspondence may remain in a host computer as data, the management, which ties an emergency measure on that occasion, also to the recurrence prevention and the lasting measure as goods from the first becomes early. Furthermore, the detail information is accumulated as a manufacture by this system, it can utilize for future product development widely.

2.4. Conclusions

This system showed a method of how to reduce the time and the process is influenced to the worker at job site. The worker at job site had read the way of installation from the drawing before starts the construction. This work was polished by experience, and it needed to work about scramble by complicated parts, having been given by the designer or the construction administrator or looking at a plan document, a handling description, a construction procedure document, etc. By having processed these books electronically, the state and position information on parts can check timely by linkage of an ADB system and APC system. The purpose of this research is aiming at that "SCM for every construction site", and each manufacture shares a owners opinion, a principal contractor and the purpose, and a target, and can be engaged in construction is made by such system.

3. Construction of an information sharing system

3.1. Increase in efficiency of the construction production by the “Parts and Packets unified architecture” system and the information sharing system

In this project, "prototype development of a parts and packets unified architecture system and an information sharing system using the Glue Logic" was hung up as an enforcement item in the 2003 fiscal year. About it, the prototype of a system was created for the purpose of the increase in efficiency of construction production, and the validity was examined.

3.2. Analysis of the problem in the construction production spot

It is almost the case for two or more companies to cooperate and to advance a process in the present construction production. And the amount of data used by one construction production process reached the huge number, and is entangled intricately among companies or in the company. However, although it is clear that these data has causal relationship, the system environment which connects it is not established by the present construction production.

And, in construction production, a detailed process plan is decided in advance, and, usually two or more companies concerned with the construction production and a section do work on the basis of a process plan. But, since various events which interfere with a process plan actually occur, the process plan decided first is changed in many cases. Since the event which blocks a process plan leads to the increase in direct cost, it needs to change a process plan so that damage may be suppressed to the minimum. But, since the amount of data used by the construction production process has huge and complicated relation, it is the present condition to have required the difficulties for change of a process plan.

3.3. Introduction to construction production of a parts and packets unified architecture system and an information sharing system

By introducing a parts and packets unified architecture system and an information sharing system aims at reduction of the increase in efficiency of the management about redundant data, and the formation of cost increase accompanying change of a process plan to the problem of construction production.

The structure of “Parts and Packets unified architecture” is made into the precondition at introduction of a system. This embedded the minute radio tag called RFID to the Construction Department article, and has pointed out beam structure with a string for ID information to each Construction Department article. It is possible to read each ID information with un-contacting type reading equipment in this article. This reading equipment is installed in the important reference point of a construction production process, and the Construction Department article pursues on real time

whether it passed at which time, or what passage status it was, and collects which places. Incidentally, in this research, the important reference point in this construction production process is called the "gate".

And, there is an active database (the following, It is referred to as ADB.) as an important base of a parts and packets unified architecture system. In ADB, when the event which checks the process plan of "apparatus having broken down", "carrying in of a material having been overdue", etc. occurs, the optimal rescheduling which suppresses the increase in cost is carried out. And it has the function to perform action, such as retaking out directions to the persons concerned engaged in construction production if needed. That is, ADB is an event drive type schedule optimization system using the incoming signal from a gate.

In addition, ADB is based on the Glue Logic currently developed at the Tokyo Electric communication university and the Takada laboratory. The Glue Logic is a base system for control which makes it possible to perform processing autonomously to a specific input.

About the information sharing system, the Web application system using the database of XML form was adopted. Since XML has the feature which can absorb the difference in a data structure flexibly, it can absorb the difference in the data format over the company engaged in construction production, and the system. By using this feature aims at integration of construction production data, employing the existing basic system efficiently.

And, the ubiquitous environment which can receive required information, without asking places, such as an office, a factory, and a construction site, is also offered by enabling perusal of the data of the construction production integrated by XML by the Internet. About the display screen, it is considering as the operation design which can pull out information by performing interactive operation on the drawing focusing on the drawing information for maintaining common recognition among construction productional-relations persons. Operation which relates required information with a drawing image and can pull it out intuitively by this is realized.

Thus, the cost generated in construction production is reduced by really parts and packets unified architecture introducing a system into the process of construction production. And by the information sharing system, the efficiency of redundant data management is increased. Furthermore, by making these systems cooperate, the system environment where it can respond to change of a construction production process promptly is built.

3.4. Prototype details of an information sharing system

The following items were made into the requirements for a system in building the prototype of an information sharing system.

The database used by the system is made into XML form.

System form is made into a Web application system.

It is made the structure where a system is connectable with ADB.

The reference function to a database is mounted.

It is made the interface in which intuitive operation is possible.

The data format of drawing information is made into SVG form.

About , XML has the feature which can absorb the difference in a data structure flexibly. Use of XML is the optimal in order to unify the construction production data over the company and the system.

About , it is possible in the Internet to acquire information, without asking a place. Therefore, the Internet shall be adopted as a means to share information among many companies. And a system is made into a Web application system and it considers as the structure which can disclose information to the Internet.

About , By cooperating ADB and the information sharing system for optimizing a schedule, the increase in efficiency to a construction production process is raised in multiplication. And ADB also enables it to use the interface of the information sharing system which can be used from the Internet.

About , the construction production data accumulated by continuing employing a system serves as a huge quantity. Therefore, a reference function becomes indispensable as a means to acquire arbitrary information.

About , the user of a system is not necessarily the expert of a computer. Therefore, an interface which can get information by carrying out interactive operation to the drawing information to display and which use tends to make intuitive shall be built.

About , in order to make a CAD drawing peruse by the Internet and to give interactive operation, SVG form is the the best for the data format of drawing information. In addition, SVG is the figure format of an XML base for a vector system expressing 2D-Graphics.

In this research, the prototype of an information sharing system was created on the assumption that these requirements for a system. An information sharing system is accessed via the Internet and the screen with which arbitrary things were searched is shown in Fig. 3.1. And the screen which displayed the detailed information on the searched thing is shown in Fig. 3.2.

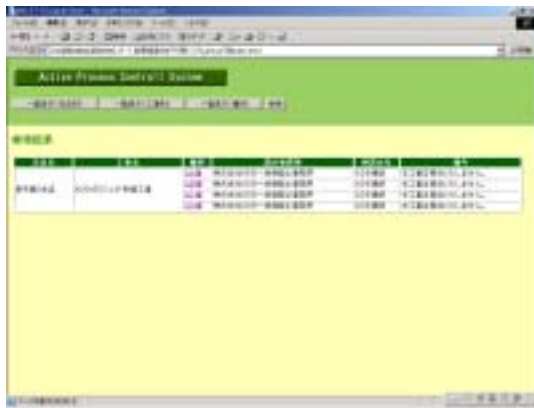


Fig 3.1 The display screen of a reference result



Fig 3.2 The detailed information screen of a reference thing

An information sharing system can be accessed by the browser through the Internet. And it is possible to search arbitrary things from a vast quantity of construction production data accumulated in XML form. The link to thing information is stretched to the reference result, and the information can be perused easily. It is possible for information to be related with the object of a drawing, to click an object, and to acquire detailed information interactively. And the structure which each object is made to display the newest process situation according to a color, grasps a process situation visually, and can start action because ADB cooperates is realized.

3.5. Conclusion

By research of this fiscal year, the prototype of an information sharing system was operated, construction production data was unified in the database of XML form, and a possibility that information would be sharable among companies was shown. And by making it cooperate with ADB also showed a possibility that it might become the high interface of convenience over the rescheduling of a construction production process.

In the prototype system built this time, XML is made to collect construction production data and this structure is set as the center of a system. It is thought that it can respond flexibly when considering range extension of the systematization in construction production, since the system based on such XML is very excellent in extendibility.

Many high things of confidentiality are contained in the data dealt with by this system. And in this system, the function of drawing management according to transition of a construction production process is not included. In consideration of these elements, the function to manage the layer structure of security strengthening of a system, and a drawing and attribute information is due to be added from now on. Furthermore, formal employment shall be put into a view and the load test and durable test to mass data of construction production shall also be considered.

4. Integrated Process Management System for Part-Manufacturing and Building Construction

This chapter describes an implementation of the Integrated Construction Process Management System using RFID's, which includes manufacturing process management features for building parts, and also includes construction process management features at construction site.

4.1. Overview

RFID's are stuck to all of the parts to be managed in order to observe the flow of the building parts, and several checkpoints, which we named "gates", are introduced within the coherent process through part-manufacturing and building construction. Every time when a building parts pass through these "gates", the RFID's stuck to the parts are read and the tracking information are accumulated into a database system. By means of this, building parts can be tracked certainly from parts manufacturers to and also within a construction site, and anyone can know the status and the location of building parts at that instant.

Furthermore, with the use of the typical necessary processing time from a gate to the next, we can know when the building parts should pass the "gates", or when the building parts will pass the final gate, i.e. completion of the final inspection process in the construction site, and whether the predicted time to pass the final gate is early enough for the overall construction schedule. With this prediction feature, parts manufacturers can judge whether their manufacturing processes are sound or not, and also judge which work-in-process should be favored within their manufacturing lines. On the other hand, the construction sites can know when their building parts should be ordered, and when the parts should be present at the construction sites.

At the gates which building parts pass at the end of each process, construction workers can judge whether the process was completed successfully or not, and this judgment can also be accumulated within a database. For example, in the case of the worker having recognized that a building parts does not pass a receiving inspection for successive processes and telling the judgment to the process management system, shortly the system reallocates from successive parts of the same type, also informs to process managers whether the final inspection can be completed before the due date and time, and even the system orders the building parts which become short if permitted.

In addition to these features, the process management system manages information intensively, and adopts the distributed agent system which can process every events reactively. These make the system easy to add new processes and user interfaces, and also easy to implement different processing features for every construction sites.

4.2. Approach

As the feasibility test of the Integrated Process Management System, the system is designed as

simple as possible in the implementation of this year. The system requires the bill of materials and the data of standard (i.e. average) processing time from the gate to the next.

As the due date and time for every building parts to clear the final inspection are defined by the overall construction schedule, the due to clear each gate can be computed using the standard processing time. On the other hand, every time when a work-in-process passes every gate, we can predict the date and time when the work-in-process is expected to pass the following gates. In this way, we obtain a set of due date and time to pass the gates, and also a set of expected arrival date and time. In order to allocate work-in-process to the requests, these two lists are sorted by the time, and each item is paired from the beginning.

In the case of a pair of time in which due time is earlier than expected arrival time, we assume that the building part will be late for the final inspection process. If the overall construction schedule is altered, or if the work-in-process passes a gate, the one of two sorted lists are altered and the allocation is redone.

4.3. The Gates

In this implementation, nine gates are established as follows. The number of gates is not ruled by the system, and the users can freely set any number of gates.

1. Design,
2. Ordering materials,
3. Starting manufacturing,
4. Parts assembling,
5. Shipping out,
6. Carry in inspection at construction site,
7. Delivery to the final stock yard,
8. Install to the building,
9. Final Inspection.

At the each time work-in-process passes the each gate, following processes are taken place;

1. RFID's are read and the work-in-process is identified,
2. Timestamp for the passing gate is recorded,
3. Physical location of the work-in-process is recorded,
4. The status of the work-in-process (whether it is sound or NG) is judged and recorded.

4.4. The User Interface

The system user interface is implemented as a World Wide Web's Common Gateway Interface (C.G.I.) application, because all system functionalities should be accessed via not only desk-top computers for office workers but also PDA terminals for plant-floor or construction site workers.

In the user interface screen, the requests and the work-in-process are represented in one row, which consists of nine timestamps, as shown below.

Type List -- Type Identifier: AW1

Type/Gate	--- GateX ---							
Date/Week	Design	Maters	Prot.	Assess.	ShipOut	Concylis	Erting	Instal
AW1	---	---	---	---	---	---	---	---
UNIT0001	---	---	---	---	---	---	---	---
Process	---	---	---	---	---	---	---	---
GenSeq0005	---	---	---	---	---	---	---	---
AA	20031030	20031115	20031123	20031127	20031129	20031130	20031201	20031201
GenSeq0001	210000	210000	210000	210000	210000	210000	060000	150000
Process	20031031	20031110	20031123	20031127	20031129	20031130	20031201	20031201
GenSeq0001	120000	120000	120000	120000	120000	120000	000000	060000
XX	20031030	20031115	20031123	20031127	20031129	20031130	20031201	20031201
GenSeq0002	210000	210000	210000	210000	210000	210000	060000	150000
Assemble	20031025	20031109	20031122	20031127	20031129	20031130	20031201	20031201
GenSeq0003	120000	120000	120000	120000	120000	120000	000000	060000
AW1	---	---	---	---	---	---	---	---
UNIT0002	---	---	---	---	---	---	---	---
Process	---	---	---	---	---	---	---	---
GenSeq0006	---	---	---	---	---	---	---	---
AA	20031101	20031117	20031125	20031129	20031201	20031202	20031203	20031203
GenSeq0003	210000	210000	210000	210000	210000	210000	060000	150000
Process	20031031	20031113	20031126	20031130	20031202	20031203	20031204	20031204
GenSeq0002	120000	120000	120000	120000	120000	120000	000000	060000
XX	20031101	20031117	20031125	20031129	20031201	20031202	20031203	20031203
GenSeq0004	210000	210000	210000	210000	210000	210000	060000	150000
Process	20031025	20031112	20031125	20031129	20031201	20031202	20031203	20031203
GenSeq0004	120000	120000	120000	120000	120000	120000	000000	060000

INF-11

Figure 4.1: User interface screen sample

A row with white background color represents a request, and contains due date and time. On the other hand, a row with green or blue background color represents a work-in-process, and contains recorded or expected arrival date and time. A request row in upper and a work-in-process row in lower are paired, and the arrival time is shown in red font if the due time is earlier than the arrival time.

In the case of any event (i.e., any due date and time, or any work-in-process passing any gate) occurs, the allocation is redone and the contents of this screen are revised.

4.5. The Information Infrastructure: Glue Logic

In this implementation, we aimed at the centralized intensive data management using an “Active Database”. “Active Database” is a subset of “Database”, which has an ability to behave spontaneously in the case of the state of the database itself changing. This state change contains;

1. A value of data altered,
2. Some relation among several data made or broken.

And the behavior contains;

1. Changing content of the Database,
2. Sending message to user or software component.

In order to implement the whole system, we used “Glue Logic” which was designed and developed by Takata Lab. of the University of Electro-Communications, as the kernel component of the Manufacturing Execution System (M.E.S.) carrying out manufacturing process control.

The Glue Logic is a minimal set of the infrastructure, which supports multiple agents running on a network environment and provides field of cooperation among them. To fulfill this purpose, the Glue Logic is designed as an active database system which can operate in the network environment. The Glue Logic manages shared memory space among cooperative agents, and when the value of the name in its active database is changed, the system sends messages telling the change information to the agents subscribing to the name. This change information also gives a cue to the recipient to start behave.

4.6. Evaluation & Consideration

The system is implemented on the Sun Solaris 8 operating system running on Sun Netra T1 processor. Items proven are as follows;

1. Reallocation is carried on only when the due date is changed greatly or a work-in-process overtakes another within the manufacturing line.
2. Reallocation takes a few seconds, because the number of work-in-process of the identical type in the manufacturing line is at most tens or so. If the type consists of a few types of parts, as the expanding the bill-of-material in multiple stages takes place, reallocation may takes ten seconds or so.
3. To prevent meaningless reallocation on the data entry, the feature to postpone reallocation process for a given period.

From the view point of the scalability, followings are proven;

1. As the gate passing information is kept within the active database system, any software agents can refer this information.
2. In order to convert from RFID identifier to work-in-process identifier, there should be some dedicated agent. Though all RFID are used to identify work-in-process in this implementation, many other usages of the RFID are supposed.

The limits proven in this implementation are as follows;

1. Reallocation is very limited in its performance. In this implementation, we did not include optimization features into the reallocation processes.
2. Autonomy is limited in its capability. In this implementation, we outweigh information sharing than autonomous processing.

3. Expected arrival time is inaccurate, as this value is computed with a constant value, standard processing time. Linkages with the Manufacturing Resource Planning Systems are needed.

4.7. Conclusion

The implementation of this year proved that the Integrated Construction Process Management System is feasible enough. On the other hand, followings should be studied;

1. Development of the problem solving knowledge to minimize overhead man-power on the reallocation.
2. The range of business operation in which the system can behave without human intervention.
3. Connection methodology of multiple part-suppliers and multiple construction sites.
4. Integrated Process Scheduling from part-suppliers to construction site.

In the following years, we would like to clear these limitations, and implement much more realistic operations.

5. Construction Automation using RFID Devices

This chapter describes a method of pose estimation of the construction components using RFID devices in order that a construction robot achieves the automated construction tasks. The identification of the device by the ID reader shows that the device is in the communication range of the reader, but does not obtain the pose of the device. Thus the identification of only single device cannot fix the pose of the component. We try to find the conditions of the ID reader and ID devices for the pose estimation, and propose an estimation method with at least two different identifications under the condition that two devices are not attached to the same plane or parallel planes of the component [1]. In this chapter, we describe our idea of the pose estimation using multiple ID devices and show the feasibility of our idea through the pose estimation experiments.

5.1. Introduction

The recent advancement of information and communication technologies has brought feasibility of efficient construction automation. These robot arms need information acquisition systems to achieve tasks in the construction site. A construction automation system based on the relation between construction components in the construction site (parts) and their information (packets) has been proposed [2]. Robots or workers obtain task information for achieving tasks via components in the workspace. The parts are strongly related to the parts information. Therefore the robot can obtain the required data for achieving tasks easily. The acquired information via the environment-attached storages improves the sensing ability of the robot.

A robot requires current pose information of the component on achieving automated handling. Since the current pose of component will be changed in the process of construction, it is not easy to store the pose in the database. In this chapter, we propose a method of pose (position and orientation) estimation of a construction component using multiple ID devices. The basic idea is to estimate a component pose with respect to the reference coordinate frame based on the movement of the ID reader and a series of ID device poses with respect to the component frame. According to obtaining an ID of the device, the robot obtains the information that the device is in the communication area of the ID reader. However, a single device cannot define the component pose uniquely. If the robot obtains a set of device poses attached on the component, the component pose can be defined perfectly with respect to the reference frame. These devices should be attached carefully on the component sides.

5.2. Pose Estimation using Multiple ID Devices

Figure 5-1 shows a method of obtaining an ID using the ID reader. An ID device is attached on the surface of a construction component. The ID reader is mounted on the robot hand, and the position and orientation of the ID reader is estimated based on the kinematics parameters of the robot. As

shown in Figure 5-1, the robot can detect the ID, when the device comes within the communication area of the ID reader. There are several problems in using ID devices: It is difficult to obtain the pose of the component that the ID device is attached. And the robot cannot obtain the distance between the ID reader and the component by detecting the ID device.

A component pose will be estimated by reading multiple ID devices attached to the component. We propose a method of estimating a component pose with respect to the reference coordinate frame. The idea is to use the movement data of the reader and the device pose in the component frame read by the ID reader. In this method, the robot can make the plan of the ID reader to read the other ID devices for pose estimation of the component using the obtained ID of the devices attached to the component.

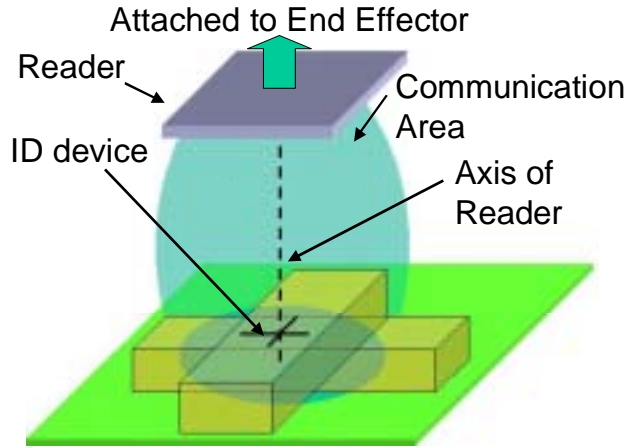


Figure 5-1 Acquisition of Data of ID Device by the ID Reader

Figure 5-2 shows our proposed idea. There are some assumptions in our proposed method. Several ID devices are attached to the surface of a component, and the poses of the ID devices in the component frame are registered in the operation server as component data in advance. When the ID reader detects a device, there is only one device within the communication area of the ID reader. The procedure of the pose estimation is shown as follows. First, the robot searches an ID device attached to the component by moving the reader. When the robot detects a first device and obtains its ID, the robot sends the ID and the robot pose to the operation server. The server searches the device pose data represented in its component frame. The server tries to find a near ID device on the component, and sends the coordinates of the next ID device to the robot for its motion planning. Then, the robot will search the next ID device.

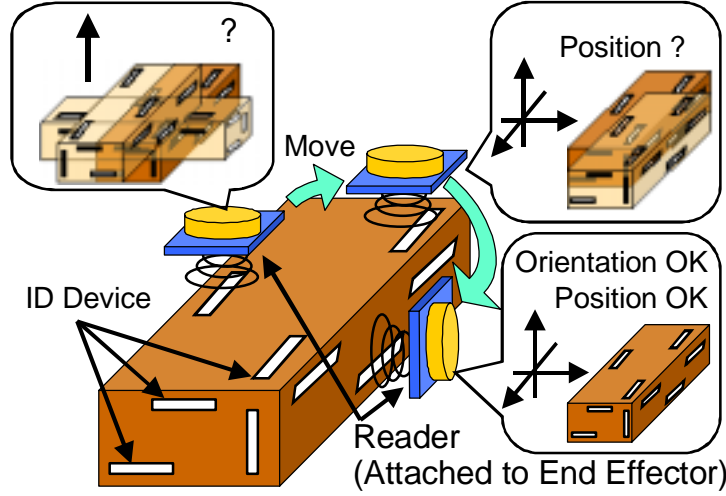


Figure 5-2 Pose Estimation using Multiple ID Devices

When the robot obtains the next ID, the robot sends the ID and the pose that the robot obtains the ID to the server. The server estimates the origin of the component frame with respect to the reference frame, that is, the pose of the component. Once the robot obtains the component pose, the robot can handle it perfectly.

In the estimation process, the correct pose of the ID reader can be obtained, since it is calculated using the robot kinematics. A series of the device poses in the component frame can be obtained by matching the IDs and the component data in the operation server. Therefore the robot can estimate the pose of the component using an ID reader without any sensors.

5.3. Pose Estimation Experiment

We have carried out a pose estimation experiment to show feasibility of our idea. This experiment is 2-dimensional-pose estimation of the component on the ground. In this experiment, the robot estimates the pose of the unknown component.

The trajectory for searching the first device is the scanning. And the trajectory for searching the second device is the circle, since the robot knows the distance to the next device when the robot obtains the ID of first device. The registered data are the ID of the device, and the position of the device with respect to the component coordinate frame. The acquired data of the robot are registered data and distance of the next device for searching second device. The distance of the devices is set 100[mm] and 200[mm].

Figure 5-3 shows the flow of the pose estimation experiment. The ID and position of each device with respect to the object coordinate frame \mathbf{p}_{o, D_x} are registered beforehand. At first, the robot search for the first device. If the reader attached to the robot arm detects the ID device, the reader obtains the ID. The obtained ID is sent to the operation server. The operation server searches the ID of the device D1. And it searches for the position of D1 using the obtained ID.

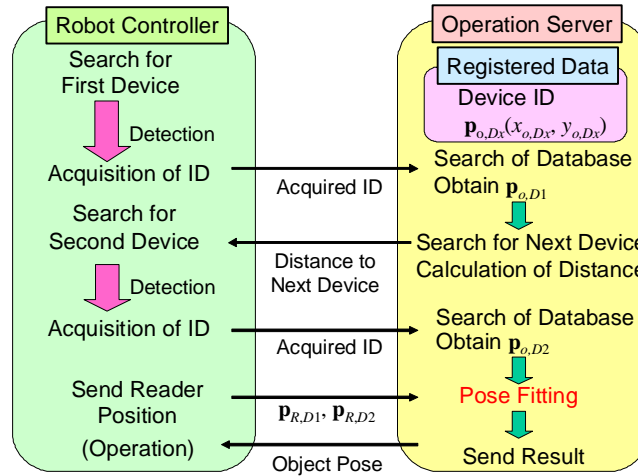


Figure 5-3 Flow of the Pose Estimation Experiment

Then the server searches for the nearest device, and estimate of the device to the next device. The distance for the next device is sent to the robot arm. The robot arm searches for the second device. If the reader attached to the robot arm detects the ID device, the reader obtains the ID. The obtained ID is sent to the operation server. It searches for the position of D2 using the obtained ID. And the robot sends the reading position to reading position of each device. Last, the server estimates the pose of the component using these positions. The pose of the component is sent to the robot arm.

Table 5-1 Result of Pose Estimation

Distance of Devices [mm]	Trial (Success/Total)	Position Error [mm] (Ave./Std./Max)	Orientation Error [deg] (Ave./Std./Max)
100	19/20	20.9/7.0/29.0	10.8/11.6/36.3
200	14/20	15.0/6.7/26.9	8.3/5.3/18.8
100 (Precise Search)	10/10	3.3/1.6/4.7	2.2/1.5/4.5

The result of pose estimation is shown as **Table 5-1**. The positions of two ID devices are in the search area that is defined by the workspace of the robot arm. The position and orientation of the object change by the trial of the pose estimation. “Trial” indicates the number of the trial times of the pose estimation. “Success” indicates the times that the robot obtains the both ID of the devices and the robot can estimate the pose of the object. (Ave. /Std. / Max) indicates the average, standard, and maximum of the position or orientation error respectively. “Precise Search” indicates the case that the robot estimates the pose of the ID device using the border of the communication area of the ID reader. Table 5-1 shows that the position error is independent of the distance of ID devices. On the

other hand, the orientation error is dependent of the distance of ID devices.

The position and orientation accuracy of the component improves by the estimation of the center position of the communication area using the border of the communication area of the ID reader. Thus, the position and orientation accuracy is dependent on the estimation method of the pose of the ID devices using the ID reader.

5.4. Conclusions

In this chapter, we proposed a method of pose estimation of construction component using multiple attached ID devices in order to achieve automated handling in construction. We introduced the geometrical relation model of a reader and a device to estimate the pose of the component.

In the future works, we will propose the modeling of ID device with the consideration of the communication area, the pose fitting of the component, the estimation of the modeling error, the automated handling of the real component.

References

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Arai Laboratory, Graduate School of Engineering Science, Osaka University

6. Integration of Information and Substance using Virtual Reality Technology

6.1. Integration of Information and Substance

Information and substance, in principle, should be integrated. However, these two are separated as information, taking a form of language or letter or digitized, is sent to a place where substance does not exist. Thus, each exists independently without having any relationship. Consequently, there are some cases where information does not convey the actual state of substance. For example, according to information, a substance has been already completed, though a substance has not been completed actually.

Recently, it has become possible to integrate information and substance, by attaching an electronic tag, RFID, to substance. This technology to attach information to substance has been attracting public attention as it may drastically facilitate the access from ‘substance’ to information. On the contrary, it is impossible to attach substance to information.

Three-dimensional CAD and Virtual Reality technologies are playing important roles in the access from information to substance. As mentioned previously, substance cannot be attached to information, it is expected to attach virtual substance to information, thus indirectly achieving the access from ‘information’ to ‘substance.’

6.2. Construction process management

In construction process management, it is necessary to efficiently prepare and transmit planning and management information. Such information is always involved with substance. Construction managers want to grasp the real-time site condition at a site office, while workers want to obtain information on the details of work and report the work progress to a site office.

In order to integrate substance and information, RFID, three-dimensional CAD, and VR technologies should be utilized effectively, thereby making it easier for managers and workers to handle information.

6.3. Construction process management based on tag information

6.3.1. Types of information tag

In the construction process, as an access to information on a substance, RFID is attached to a substance. Here, RFID that is attached to a substance (e.g. a component) is called ‘tag.’

The following seven types of tags are used at a construction site:

- (1) Element Tag
- (2) Material Tag
- (3) Package Tag
- (4) Equipment Tag
- (5) Activity Tag
- (6) Position Tag
- (7) Management Tag

The above tags are attached to the components of a building under construction, according to the work progress. Here, a position where to attach a tag is extremely important for the future information management. A position should be registered on the VR system when attaching a tag, so that a position can be grasped as information.

6.3.2. Grasping a position of tag with VR technology

In building construction, many people and organizations are involved until parts and components are placed into a building. RFID secures the access to information on activities of these people and organizations. However, it is inevitable that many tags exist, as each organization attaches a tag separately. Accordingly, many tags are attached to one part or component, and each position has an important meaning.

6.4. Construction process management by VR technology and RFID technology

6.4.1. Scenario applied to construction process of window components

In order to examine how VR technology in cooperation with RFID technology can be used in the construction process management, a scenario applied to the construction process of window components is discussed below.

It is assumed that window components delivered from a factory should be installed in a building according to the following process:

- (1) Delivery from a factory to a stockyard at a construction site
- (2) Transportation from a stockyard to a work site
- (3) Installation at a work site
- (4) Inspection (i.e. quality management)

Here, it is assumed that sashes and glasses should be delivered together, and transportation and construction should be conducted at the same time.

6.4.2. Delivery from a factory to a stockyard at a construction site

When window components are delivered from a factory or a warehouse to a construction site, a site office should confirm the acceptance of these components.

Delivered materials are temporally placed in a stockyard, and unpacked. In the confirmation of acceptance, it is necessary to read Package Tag and/or Element Tag. Then, by collating these tags with the building document, it is possible to confirm whether a delivered component is needed at that time, and whether the delivery time is too early or not.

6.4.3. Transportation from a stockyard to a work site

Workers can identify the destination of transportation by reading Package Tag or Element Tag attached to the components to be transported. Based on the information, workers transport sashes and glasses to a target room. After the transportation, workers will read Position Tag attached to a target room in order to confirm whether components are installed in the right place (See Fig. 6.1). Thus, information showing that the transportation has been carried out correctly can be transmitted to a database in a site office. Using Position Tag, a position of components after the transportation can be visually confirmed with VR System at a site office.



Fig. 6.1 Components transported and installed in a room

6.4.4. Installation at a work site

Workers install components based on a job order. By reading Element Tag attached to the components to be installed, workers can obtain information such as installation procedures and precautions from their mobile terminal. Moreover, as Element Tag information can refer to the building document, workers can obtain information such as details and a position of the installation.

After the installation, Activity Tag showing the work history is attached to the installed components. Then, the date when the work is carried out, the name of a

responsible person, and comments on the work (e.g. self-inspection report) will be sent to the appropriate database.

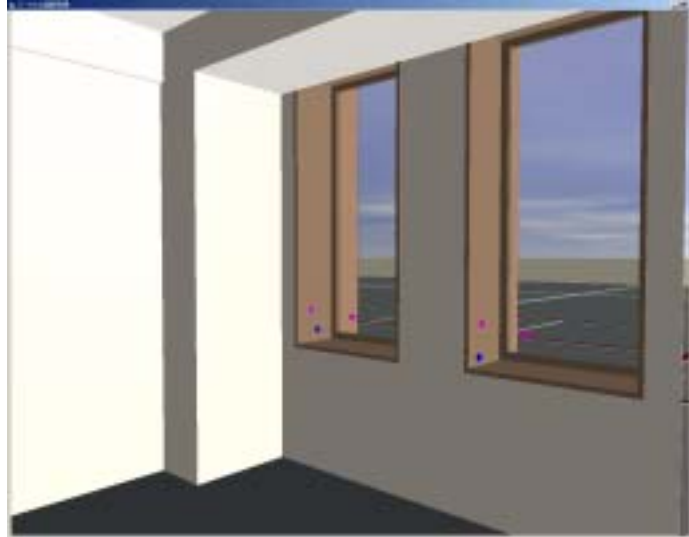


Fig. 6.2 Work site after the installation

6.4.5. Inspection

After the installation, construction managers confirm the result of activities. In general, a responsible person conducts self-inspection on activities. However, a company (i.e. a general contractor) responsible for the quality of construction as a whole is also required to conduct inspection.

6.5. Conclusion

Integration of information and substance has been an important issue for building construction. However, the advantages of integration have not been actively discussed so far due to the lack of technology for the integration.

In building construction, planning comes first; then, a substance is made. On the contrary, in the situation where the work is completed after parts and components have been actually assembled at a work site, substance comes first; then information is required.

The efficient integration of information and substance in both directions should be the basis for planning and management of building construction, as well as for efficient activities at a work site. The future challenge is how to integrate the methodology of RFID technology and that of VR technology. This chapter shows the methodology using a scenario applied to the construction process of window components as a case study.

7. Integration by process engineering and 3D-CG Simulation

- Product design, production system design, and workstations system design about “Curtain Wall” construction work -

7.1. Introduction

The research in the last fiscal year, we have indicated a conceptual framework of “Cyber Concurrent Management (CCM)” system. Then we proposed the concept and method for verifying modeling and validity of a concurrent engineering process considered a virtual manufacturing process and a real-time based manufacturing process by the various 3-dimensional computer graphic (3D-CG) simulators. As a case study for that, we built the test bed system for the verification method of modeling according the construction process of the "curtain wall" which constitutes the exterior wall of a high-rise building to a process engineering tool (it is henceforth called PE tool), and the model data based on various 3D-CG simulators.

In the research in the current fiscal year, in order to continue the research in the last fiscal year and to specify in detail the construction process of the curtain wall materials which are case studies, classified into each stage of (1) production design, (2) production system design, and (3) work system design, and the method of modeling in detail with PE tool was proposed. Furthermore, how to verify the result of the model data of (1) to (3) by various 3D-CG simulators was shown. And it was applied to the case study which develops the proposed project of the integrated curtain wall construction process.

Fig. 7.1 shows the research background in the current fiscal year from the last fiscal year.

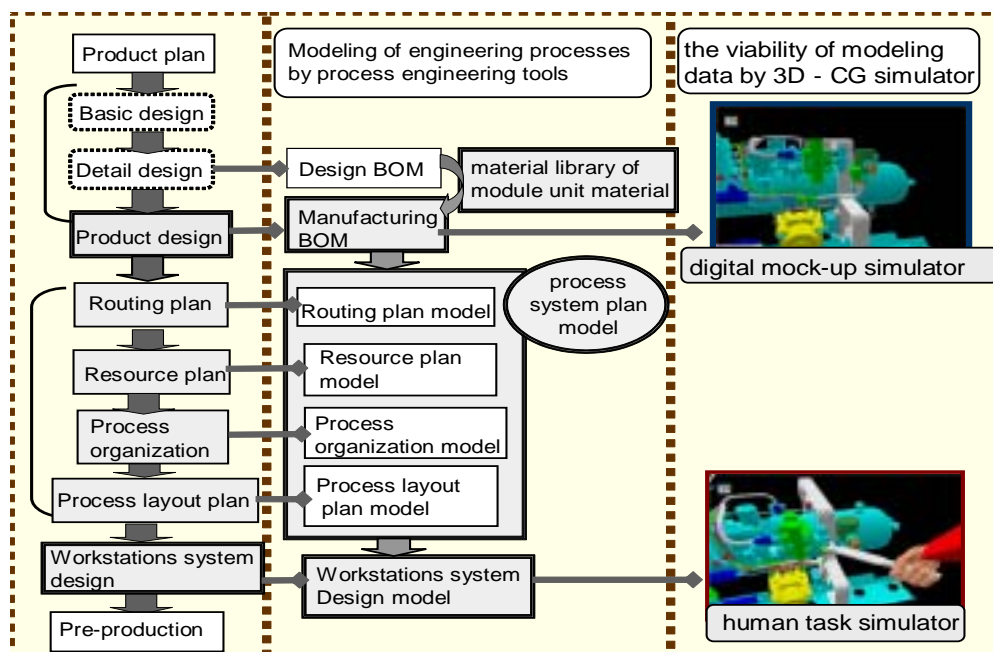


Fig. 7.1 The research background of the last fiscal year to this fiscal year

7.1.1. The research subject of this fiscal year (the 2003 fiscal year)

Fig. 7.2 shows the modeling of the construction process, and the research field verification of the modeling data in the current fiscal year. Henceforth, the research subject in the current fiscal year is described using this figure 7.2.

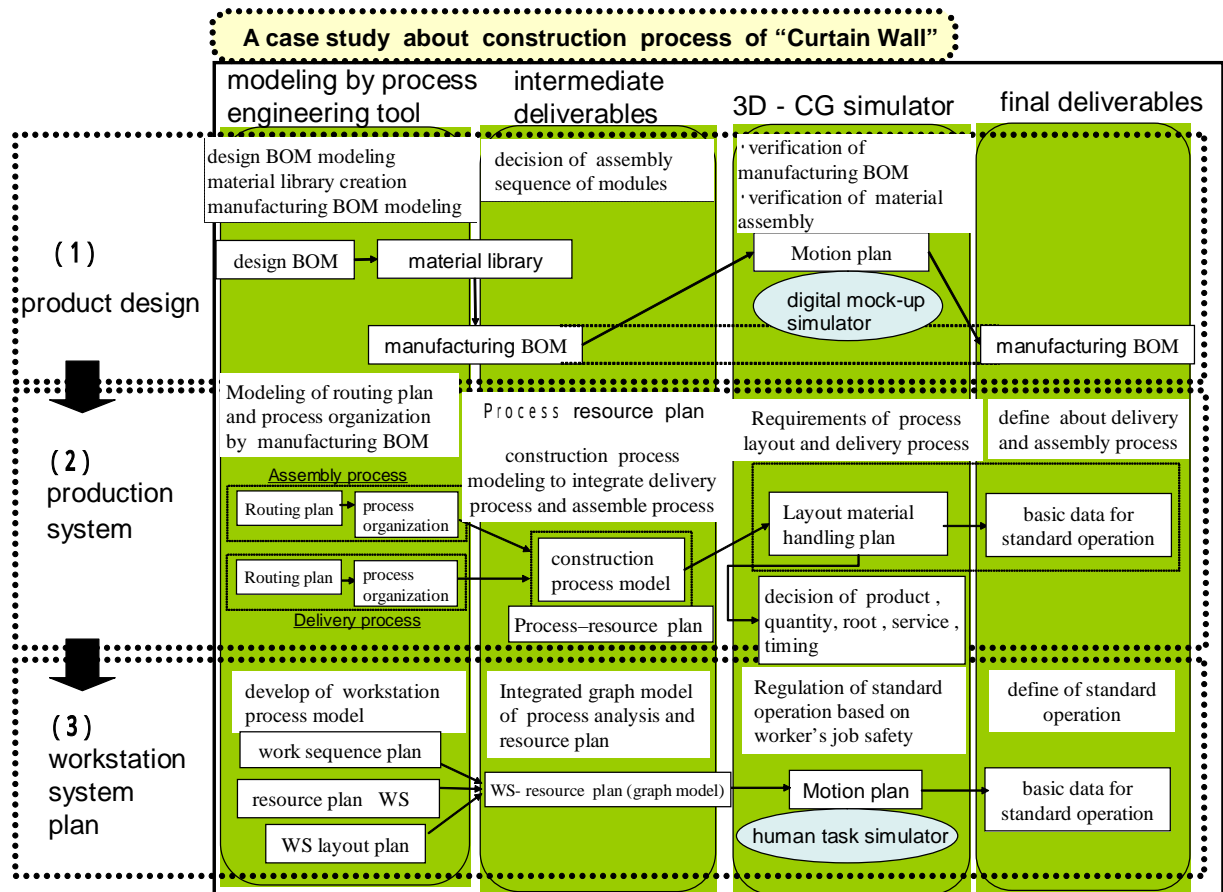


Fig 7.2 The research range of modeling of the construction process and model data verification in the current fiscal year

First, using PE tools, as it is in the left side of Fig. 7.2, modeling of each stage of construction process is performed as follows: (1) Production design, (2) Production system design, and (3) Workstations system design. That is to perform: (1) Product design which design for assemble and assembly sequence based on the material design data of curtain wall materials, (2) Production system design based on the assembly order of Product design, and (3) Workstation system design paying attention to operation in which man assembles materials.

Next is "intermediate deliverables" of the construction process data of each stage in PE tools. (1) Production design: storing to the library of materials and conversion to Manufacturing BOM(bill of material). (2) Production system: integration of assembly process and a delivery process by the

resources plan. (3) Workstation system design: work organization of two or more work contractor's group work is carried out by the resources plan.

Furthermore, the validity of the process data of each construction stage is verified by the 3D-CG simulator, and the basic data of the verified production BOM as a "final deliverables" and a work standard document is created.

Since the construction process of such each stage is modeled, the technique called process engineering is used. A tool for that is the Process engineering tool, and we will use "DELMIA Process Engineering (DPE) made by Delmia Japan Corp".

The research subject of this fiscal year is described in subsequent (1) - (3).

(1) Modeling of an operating process and model data verification of a production design stage

As a precondition, in the detailed design stage of a product design, curtain wall materials are divided per module materials based on Design BOM, and the materials library is created. Next, in a production design stage, Production BOM is created by examining the assembly order of the modules in a materials library, and the assembly order of the parts in a module, and determining the assembly order and the assembly method of the whole product. Below, the procedure of operating process modeling of a production design stage is shown.

Modeling "Design BOM" upon the part drawing of the detailed design stage of a product design.

Modeling "material S library" out of module materials based on the part information on Design BOM.

Modeling "Production BOM" based on a materials library.

Moreover, in case of modeling production BOM from a materials library, the model data would be verified by a digital mock-up simulator. "ENVISON/ASSEMBLY made by Delmia Japan Corp" is used as a "digital mock-up simulator" which performs modeling data verification of such a production design process.

(2) Modeling of the operating process of Production system design stage

According to a construction program, it is necessary to deliver required materials, tools, machine, etc. in the construction process of a curtain wall to the working area or a destination. Moreover, according to a construction program, it is necessary to assemble the delivered materials, carrying out suitable work organization. The following procedures perform such a construction process as modeling of the production system design by process engineering.

The routing plan of materials assembly work

Process organization of the materials assembly work by two or more work contractors

The resources plan for a delivery process

The process layout plan of the construction place corresponding to the delivery process

Furthermore, a construction process is modeled to fit the timing of assembly process and delivery process.

(3) Modeling of the operating process of Workstation system design stage

Workstation system design is performed focusing on the work routing of the human being for each workstation after process organization (workstation unit). That is, in Workstation system design, the work process "using what resources workers use and what operation they do" is designed in consideration of man's workability. Modeling of the Workstation system design by process engineering is performed by the following procedures.

The work routing plan corresponding to the materials assembly

Resource plan required for materials assembly work

The workstation layout plan of a working area

A setup of the prerequisite of the motion plan of work organization of two or more work contractor of operation

Regulation of the motion plan of work organization of two or more work contractor of operation, and analysis of work load

In case verifying the validity of modeling of a work system design using a human task simulator, analyze load mitigation and working efficiency paying attention to the workload and the workability of human work. Moreover, the basic data specified in "the plan of parts of operation" which is that the production BOM validated in the above-mentioned production design stage used for the basic data of a work system design.

"ENVISON/ERGO made by Delmia Japan Corp" is utilized as "a human task simulator" which verifies the work process for human.

7.2 Conclusion of the research of this fiscal year and the research subject of next year

This fiscal year focused on "modeling of the operating process by process engineering", and "verification by the simulation of model data", and proposed modeling and its verification method of the operating process production design / production system design / workstation system design in connection with construction of curtain wall materials.

Moreover, we suggested the work standardization for carrying out cooperation business efficiently between companies and sections, the application method and modeling of a process engineering tool

First, the research result of this fiscal year is shown below.

(1) Production design

Based on Design BOM", created the structure which can respond to two or more product kinds and option materials flexibly by dividing to the module materials of curtain wall materials and changing those module materials into a "materials library".

Moreover, in order to create "Production BOM" from the "materials module" stored in this materials library, it is necessary to determine the assembly method and an assembly order about the materials between materials modules and in a materials module. When determining the assembly method of between such materials modules and materials, and an assembly order in detail, the " motion plan " was drawn up using the digital mock-up simulator. In the "motion plan" using the digital mock-up simulator, the position and interference holding vertical material, relation with an orbit of operation, etc. set up some preconditions, and the existence of the interference at the time of length material attachment, a setup of the space in which motions are possible.

(2) Production system design

The model was created for the operating process of materials delivery and a materials assembly with the process engineering tool, and the method of carrying out the model notation of making both processes agreeing was shown. Integration of both these processes realized the modeling of the operating process in connection with process organization at large "which worker works in a required work area using the materials and quantity of a required kind at the time of necessity."

(3) Workstation system design

The model notation of the structure of the group work by cooperation, i.e., the work organization, was carried out with the process engineering tool among the workers who become the standard and the workers of 1 upstairs of a construction story. Furthermore, the analysis to the posture and work load of human work which attaches vertical material was shown by applying a human task simulator. By performing load analysis of modeling of the process of these human task, or human work, data can be used as basic data these results at the time of creation of a "work standard document."

Next, the research subject of next year (the 2004 fiscal year) is shown below.

(1) The procedure of modeling of a material table and presentation of an indicator

Module and the library of materials would be created using Design BOM, and the structure of the conversion method of BOM (bill of materials) would be established about the procedure changed into Production BOM from a library. First, the logical structure of "module of materials" which can respond to a product kind, the production plan of materials, a construction plan, and the procedure

plan of a process, and the library corresponding to the module will be examined. Furthermore, the structure changed into Manufacturing BOM from a library and the structure interlocked with the procedure plan of a next production system design stage as program data are combined, and the method of composing and using Manufacturing BOM in integration will become a procedure.

(2) Enforcement of the modeling of the assembly process of the main materials in two or more work place

In the production system design stage in the current fiscal year, it limited to the operating process within one work place focusing on delivery and the assembly of vertical material, and detailed modeling was carried out. Next year, it will be able to respond to the construction plan in two or more work place, and the modeling about the assembly process of the vertical material which is main materials, and a transom, and work organization of a worker would be performed.

(3) Procedure of workability and the analysis method about human work

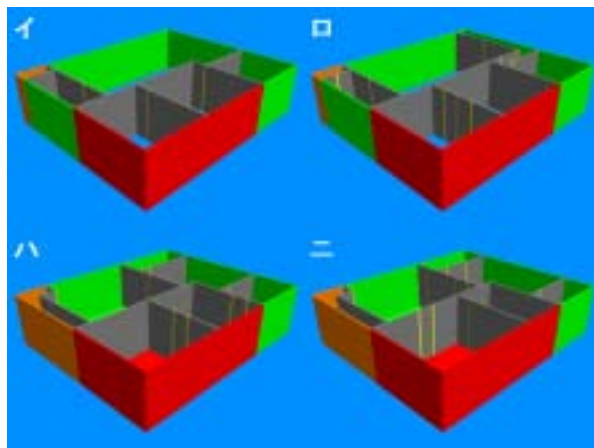
Indicate the analysis method for the load and the workability of human work, and make procedure for man's work process using the analysis method. For example, man's work process is designed, verifying work operation scientifically using the analysis method by calculation the standard time, or calculation of the amount of energy consumption.

8. AL-Based Design Assistant Systems for Parts/Information Integration Paradigm

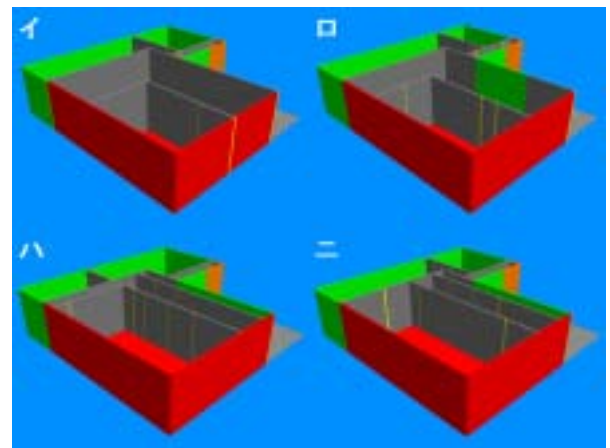
We have developed an autonomous design assistant system for generation of floor plans of common houses based on the Movable Finite Automata (MFA) theory from the field of Artificial Life (AL). This study aims at developing a life-cycle oriented construction assistant system, concept of which was proposed and reported in earlier reports. A life-cycle of a building may consist of multiple phases as, design, construction, delivery, maintenance, remodel, reuse and waste. Smart parts, the focal point of this project, are capable of contributing to the health of a building throughout its life-cycle with information that they contain. The life-cycle oriented construction assistant system takes advantages of this feature of smart parts, noting that smart parts can be considered as primitive artificial life-forms. This system can contribute in the first phase of designing a building and in the maintenance phase by serving as a base of incoming information from smart parts and in the remodeling phase by selectively reactivating artificial life-forms in a target remodeling area to create a new floor design for remodeling.

We construct a floor layout plan generation engine that is capable of generating floor plans autonomously and two design assistant systems, specifically aiming at the design and the remodel phases, utilizing this engine. The developed engine exploits MFA technology by treating unit inner walls as artificial life-forms with predefined attributes. A floor plan is generated emergently from reactions of those artificial life-forms according to a set of local rules. This makes it possible to generate a variety of floor plans totally autonomously. It is noted that types and numbers of rooms generated by artificial life-forms cannot be fixed but can be steered at some degree by adjusting their attributes, their motion characteristics and population densities of different types of artificial life-forms.

The design assistant system for the design phase generates floor plans based on rough preference of customers. It takes such preferences as numbers of big/medium/small bedrooms, general location of a living room, a dining room and a kitchen as inputs from a customer and uses them in controlling interactions of artificial life-forms, which represent inner walls of various lengths. The developed system takes the drawing of outer walls as an input to define the field of interaction for the artificial life-forms. The outer walls are partitioned into two categories, one for individual rooms (bedrooms) and the other for common purpose rooms such as a living room and a kitchen. There are two versions of the design assistant system. Version 1 divides the interior of the house into two regions similarly as the partition of the outer walls. Then the floor plans are generated for two regions separately. In Version 2, a corridor from the entrance to the common area is generated first before other rooms are formed. The entrance is marked on the outer walls prior to this operation. A set of examples generated by the developed system is shown in Fig. 8.1. (It is noted



(House shape A)



(House shape B)

Figure 8.1: Two sets of floor plans generated by the design assistant system for the design phase.

that this set of figures is shown to the customer as a part of a questionnaire for his/her evaluation.)

The design assistant system for the remodel phase considers expansion of the house and disposition of a kitchen, a bath unit and other facilities in addition to generating a new floor plan. The developed assistant system has a GUI for customer input session. A customer can enter such items as an area of the house for remodeling, an area of the house for expansion, a general direction of water related rooms and facilities and problems of his/her current house. The system takes the design of the current floor plan, which is generated by artificial life-forms in the design phase and is an aggregate of dormant artificial life-forms (e.g., inner walls, outer walls and household facilities), as the basic input. It not only selectively revives inner walls in the area chosen for remodeling but also selectively activates outer walls of the area chosen for extension and household facilities in the remodeling area. It can also utilize existing CAD data of facilities, such as a kitchen cabinet and a unit bath, from their manufacturers' catalogues to replace the ones in the current house plan. A set of a current floor plan and a remodel floor plan based on the current floor plan is given in Fig.8.2.

It is pointed out that those two design assistant systems can also help customers to clarify their preferences. Most customers cannot express their preferences explicitly either in the design phase or in the remodel phase because of a lack of professional knowledge on floor plans and construction. Instead, they show their preferences on floor plans in words like "3LDK" or "a large south side living room." It is also the case in the remodel phase that customers can only state their troubles in the houses they live instead of telling how the house should be remodeled. The proposed design assistant systems are able to process both of such vague requests and dissatisfaction of a customer and to generate various floor plans that satisfy their requests or solve their problems. Both of them are capable to show the plans not in 2-D diagrams but in 3-D graphics in order to

enable customers to easily recognize characteristics of the generated plans. From those plans, customers can choose suitable ones according to their preferences. This can also help an architect to understand the customer's preference more specifically, which is a non-trivial job and time consuming. Thus the proposed system can contribute in reducing both the construction time and money in this respect as well.



(a) Original layout



(b) Generated remodeling plan

Figure 8.2: A remodeling plan generated by the design assistant system for the remodel phase.

Capabilities of the developed systems in reflecting customers' requests are evaluated by running the both systems with requests of mock customers. Evaluation is done by asking them to answer a questionnaire on generated floor plans. Satisfactory evaluations are obtained in most questions on how well the generated floor plans reflect the customers' preferences. High scores are obtained for a question on degree of variations in generated plans. This implies that the both systems can generate variety of floor plans and that endorses the intended capability of the floor plan

generation engine. It is also found, as expected, that the variation in floor plans is more limited when the set of preferences of the customer is more specific. General acceptance of floor plans generated by two versions of initial design phase, namely one with and without a corridor, is about the same with slight advantage in Version 2 with a corridor.

(This chapter is prepared by R. Nishiyama, M. Ebisui and K. Tomiyama at Aoyama Gakuin University.)

9. Conclusions

Robotics application for construction may be transformed into more subtle form not to mention the further development and versatile application of standard ‘mechanical’ robotics, not excluding humanoid robots. Because of newly developed RFID technology, and emerging nano technology to come, it has and will become more real that physical part and information packet are merged into one, and no longer distinguished for application. Once nano-level computer be realized and prevailed in the market, every part will even ‘think’ on its own with some sensor. The construction process, which is of our primary concern, may be regarded as integrated both temporally and spatially flow of unified part-packets whose span of flow covers from factory, through distribution, to every part of construction site. The management and control of such flow becomes of critical issue. The Glue logic or active data-base was proposed as a possible control mechanism, which is a giant collection of distributed controllers (sequencers) and could be regarded as virtual “Robotics” which the giant controller controls. Parts and packets are thus unified. Every component to be controlled has both poles of information and physical aspect with its integrity. The controller is now a transmuted “operating system” for production, which manages both physical and informational dipoles.

Construction production characteristically differs from that of manufacturing, which may be properly termed as a “production project”. One of a kind production becomes of a more central issue even in the manufacturing domain, as versatility of products is demanded by consumers for their available choice to meet their further satisfaction. It is not exaggeration to say that one of a kind production is exactly the way how to construct buildings ever since the onset of construction in human history. More importantly the production process itself is more or less of one of a kind for construction. There available are diverged construction methods at hand as well as construction materials to be used. The term “production project” is defined as “*a production whose projectile path is a course of concerted action intended or considered possible with dynamic alteration of choice to achieve some chosen product for a given period of time under some given constraints on available resource*” A production project as defined such confronts with two basic issues to resolve in its most general term. Firstly, it must hold itself continually, moment to moment, upon the flood of disturbances, both internally and externally originated, it must achieve a dynamic equilibrium upon a sea of waves of disturbance. The inevitable disturbances cause activities in production to fluctuate as for their completion dates. Their assigned completion dates face inerasable uncertainty so that they are stochastically fluctuating. Secondly, closely related to the first issue, but of distinct nature, a production project

requires making decisions swiftly to amend its course of action upon disturbance.

The controller system of production using RFID which this project thus developed provide an affirmative expectation to achieve a disturbance prone production for construction, in a sense that although disturbances may persist, the controller's recovery mechanism cancels out any disturbance by its dynamic change of optimal process time to time. A timely change in the course of construction greatly reduces the amount of loss of resource per se.