A SURVEY OF PRECAST CONCRETE SYSTEMS USED BY FUJITA

by

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1 INTRODUCTION

This report presents a process model which can be used to analyze the precast concrete process as practiced by the Fujita Corporation. It is the basis for a collaborative research program to develop methods to better manage the precast concrete process from design through manufacturing to construction. The document is the result of a year of studying the precast concrete process though visits by our researchers to Japan and Fujita researchers and managers to the United States. This section orients the reader to the CIC research program at Penn State and the Penn State - Fujita Research Collaboration.

1.1 Computer Integrated Construction (CIC)
The CIC Research Program at Penn State was established in 1987. The first project, an NSF grant stimulated the development of the Integrated Building Process Model. Since then, several agencies and companies have funded our CIC research.

The long range goal of this CIC research program is to create an integrated project environment similar to that of the master builder of yore - a Virtual Master Builder environment for projects. The goal is to improve the process of providing a facility and to develop integrated tools that assist in providing cost effective, timely, necessary facilities to users. We see this research as a partnership with leading researchers, government and corporate leaders, faculty and students.

The program has two components, basic research and applied research. Basic research consists of understanding the fundamental principles behind the way systems or processes work. In themselves, they are of little use to the industry, but they provide the essential models that are used in applied research. Applied research focuses on developing solutions to specific industry problems. Our basic research is conducted through federally funded projects, grants and consortia, while applied research is developed for specific clients under separate contracts.

1.2 Penn State-Fujita Collaboration.
This collaboration began in April 1991 with a grant to support the basic research components from Fujita. The National Science Foundation provides matching funds for such operations under the Presidential Young Investigator Program. The current agreement provides an annual amount for this basic work, and the mechanism for developing specific applied research such as prototypes, under separate funding. During this first year we have developed process models of the precast
concrete (PC) process practiced by Fujita. We are also speculating on prototypes for development in the following years of the collaboration.

This report is written in collaboration with the Fujita Corporation. The information for this report has been obtained through visiting the Fujita design offices, the Chiba Precast Concrete Manufacturing Plant, and the Misato New Town and Koriyama Mitsubishi PC Sites. Additional information was obtained through interviews, and correspondence and questionnaires with many of the Fujita employees involved in the PC process. Several key Fujita researchers and managers visited Penn State several times. The literature published by the Fujita Corporation and many others were also reviewed.

This report is the first attempt to communicate and refine our goals and focuses in the coming years. The precast concrete process model and information architecture which are contained in this report are taken to a detail level which is sufficient for understanding the basic elements in the entire process. In the next phase of the research project, the collaboration will focus on developing more detail in specific areas of the different models.

1.3 Reader's Guide
This report orients the reader to the project. It then describes the precast concrete (PC) systems used by Fujita (Section 2) and the current computer systems used in the PC design, manufacturing and construction processes (Section 3). Section 4 describes the IDEF0 modeling method and illustrates the first level of the Integrated Building Process Model. The first three levels of the precast concrete process model are presented in Section 5. The subdivision of the PC processes are verbally described while IDEF0 process diagrams further represent the processes. Section 6 defines and classifies the information required to drive the different processes. Appendix B is a glossary that defines all the terms used in the process and information models.

In the final sections of this report, the current PC process model is compared to the Integrated Building Process Model (IBPM). This shows some areas of the PC process which could be researched in more depth. In the appendix of this report, all the different information elements contained in the process model are defined.
2 PRECAST CONCRETE SYSTEMS

This section defines the precast concrete (PC) systems or methods used by Fujita in Japan. It
defines 8 types of PC applications performed by Fujita. A brief discussion of benefits of the PC
method conclude the section.

2.1 Introduction

Precast Concrete Method is defined by the Fujita Corporation as:

*An industrialized system of building construction where standardized members are
cast and manufactured in the factory before being erected into their position in a
structure.*

This definition was created before Fujita started to use site PC, so the definition has been modified
for this report to:

*An industrialized system of building construction where standardized members are
cast and manufactured at a location different than their final location and then
erected into their position in a structure.*

2.2 PC Method Background at Fujita Corporation

Fujita Corporation is the second largest precast concrete contractor in Japan. Fujita completed its
first PC project in 1968 (Tsurugaya Housing Estate No. 3). As of July 1991, they have used PC
in buildings totaling more than 900,000 m² (9.7 million ft²).

Fujita typically uses the PC method on design build contracts, but also competitively bids
construction of PC buildings where the design is supplied by an architect or engineer. Typically
the site labor is subcontracted to companies that depend almost exclusively on Fujita for their
work. Fujita owns a PC factory in the Chiba Prefecture where many PC elements are fabricated.
The balance of the PC elements are cast on site or purchased from a supplier factory.

2.3 Types of Precast Concrete

The following types of precast concrete methods are used by the Fujita Corporation:

- Low-rise Precast Concrete (LPC): This precast concrete system is used in low story
  housing structures (from one to three stories). The system is primarily used in areas where
  building height and scale are restricted by regulations, zoning, development control, and
environmental factors. The precast units in this construction method are composed of walls, floor, and ceiling. Since no columns or beams are needed, interior space can be maximized.

![Diagram of LPC Method](image)

**Figure 1.1 - LPC Method**

- **Wall type Precast Concrete (WPC):** This precast system uses wall, floor and roof precast panels to create a building. This is a method which is used for the construction of apartments buildings from three to five stories.
Eleven Story Precast Concrete (EPC): This construction method was developed by the Fujita Corporation. This method eliminates the use of columns and beams by using precast reinforced concrete wall panels for structural members. The method is used on projects from six to eleven stories.
- Rahmen (rigid frame) Type Precast Concrete (RPC): In this system, PC columns and beams form the structural frame for the building. These members are precast as single elements. Precast concrete floor, roof and wall panels are used to enclose the space. This method is used in buildings from one to seven floors.

- High-rise Precast Concrete (HPC): This method uses cast-in-place reinforced concrete columns with precast beams, wall panels and floor panels. This method is most suitable for constructing apartment structures from 10 to 15 floors in height.

![Figure 1.4 HPC Method](image)

- Steel-frame structural Precast Concrete (SPC): In this system, steel framing members are used with precast reinforced concrete members to create the structural frame. Precast panels are used for floors and walls. This method provides large open spaces with a high resistance to seismic loading.
FRPC: In this method, the columns are precast concrete, and the beams and floor panels are half precast concrete. There is a topping layer of cast-in-place concrete which ties the structure together and provides the structural rigidity required by the Japanese Building Codes. This method has been used by Fujita on 30 projects and it has shown a construction time decrease of 20%. This is currently a very popular precast concrete method in Fujita.

Grade Beam PC Method: This method of construction uses precast concrete elements for grade beams. Cast-in-place concrete is used to tie the grade beams to the pile caps or
footings. This method is effective in saving time and labor during the foundation phase of a project.

Figure 1.7 - Grade Beam PC Method

- PC Curtain Walls Method (CW): In this method, precast concrete elements are used to construct the curtain wall of the building. This method can be used with almost any type of structural system. The advantages of using a PC curtain wall systems are a lower cost, superiority in fire protection, free formation, thermal insulation and sound proofing, and the possibility of many varied designs of PC elements.

2.4 Reasons for Selecting Precast Concrete vs. Cast-in-place Concrete
There are many factors considered by the designer when selecting an appropriate structural system for a building. This section compares the use of precast concrete to cast-in-place concrete for a structure.

Precast concrete construction provides the following advantages over cast-in-place concrete construction:
- There is a reduction in schedule duration for the building.
- There is considerably less construction pollution such as noise, vibration and dust since less construction activities are occluding on the site and the schedule time of the project is decreased.
- There are fewer construction workers required on the site which decreases the risk of construction accidents.
- The quality of the elements is higher. PC elements can be produced at a manufacturing plant under strict quality control and inspected before leaving the PC plant.
- The labor costs may be lower for PC elements since it is more efficient to produce the members in a PC plant than on the construction site.
- The impact of adverse weather has a small effect on the cost of elements and the production schedule.
- The PC method allows Fujita to:
  - Use lower skilled labor to produce an element of PC.
  - Increase production of elements for a given labor force.
  - Concentrate manpower in fewer design centers in the company.
- The cost of auxiliary materials such as formwork, scaffolding, etc. is lower.
- Fujita has greater flexibility in construction methods.

Precast concrete construction however has the following disadvantages when compared to cast-in place concrete:
- It may be difficult and expensive to transport when the site is remote or the elements are large.
- PC may be more expensive in some areas where skilled site labor is cheap.
- There are considerably less laborers and engineers familiar with PC systems than cast-in-place concrete.
- PC elements may require a larger member for the same structural capacity as a cast-in-place element. In many cases the thickness of the PC element is neglected in the structural calculations.

The following section outlines current computer applications which are used during precast concrete construction at Fujita.
3 EXISTING COMPUTER APPLICATIONS

Fujita has designed several computer systems to support the design and detailing of PC elements. Descriptions of some of these computer systems follow.

COMPASS
COMPASS is an architectural design program which is currently being used by the Architectural Design Department. This system is very popular in Fujita, and it is used on almost all projects. The COMPASS system will help the designer create a 3-dimensional (3-D) model of the building and the system will then use this data to either create 3-D perspectives for presentations or 2-D drawings and finish schedules for use in other design processes and for the construction of the building. The information elements in the COMPASS system are stored as items with attributes. For example, the system will know that a line or group of lines is a beam and it will provide the area, location, and preliminary estimated cost of that beam.

BUILSYS
This is the structural analysis program which was developed by Fujita 15 years ago. The program is very long and it is written in FORTRAN, which makes updating the program very difficult. The program however is very comprehensive and performs all the structural calculations required by Japanese Law.

To run this program, a user must first create a batch file which contains a sequential list of all the information about the building. This is a very labor intensive and complicated input system. After the data has been entered, the program will perform all the structural calculations. The system will then print a detailed structural report on the project. This program is run on an IBM mainframe computer. A new structural system is being planned. This system would integrate with the COMPASS architectural design system to make the data entry for the structural system much easier and less labor intensive.

Alpha 5
This program is a commercially available 2-dimensional CAD system. It is used by the PC Department to create the detailed drawings of the PC element and joints. The entities in this system do not have any attributes, therefore a line is just a line, and cannot have the properties of a beam, column, etc. Some of the functions which are useful are length, angle and area options. This
program is run on NEC PC-9800 computers. The system has been used for 5 years, and one of the problems with the program is that it is difficult for a new user to master the available functions in the program. There are currently no interfaces between this CAD program and the other design programs in Fujita.

**FCAPPS**
This is a program which was developed at Ichiken. This program will develop a set of 2-D drawings for a PC element from the parameters of the member. The system is currently used by some branches of Fujita which are located a long distance from the Tokyo Branch (the location of the PC Department). This program runs on a NEC PC-980 series computer and the program can be stored on a single floppy disk.

**DEK**
This is another PC program which was developed at Ichiken. This program was developed for the following reasons:
- To communicate to the subcontractors the PC element sequence for the project,
- To monitor the progress of construction of PC elements,
- And to provide directions to the truck drivers of the PC element delivery trucks.

At the beginning of the project, the PC elements must be entered into the system by using the CAD drawing functions in the system. If the the shape of the building is complex, the members of Ichiken will assist in inputing the geometric information. The sequencing of the elements must then be entered into the computer. After this information is entered, the system will generate the work orders for the project for each day. The system will also display the construction sequence through a 3 dimensional display so that the subcontractors on the site can see the planned sequence of PC member erection. This system is currently being used at some FRPC sites.

**ECONSTER & FACT**
These are programs which are used by the Estimating Department to produce a detailed estimate. These programs are capable of reading computer quantity takeoff forms. Then the programs will calculate an estimated cost for a building after the user decides on a unit cost.

This concludes our description of Fujita's computer systems used for precast concrete buildings.
4 IDEF0 PROCESS MODELING METHODOLOGY

In order to accurately represent the PC process as practised by Fujita, the research team developed a PC Process Model. This model was developed using the IDEF0 modeling methodology. This section describes the IDEF0 methodology and illustrates the first level of the Integrated Building Process Model (Sanvido 1990), a model developed to represent the essential functions required to provide a facility. Note that a portion of this text is drawn from Chung (1989).

4.1 The IDEF0 Modeling Methodology

In this section, the ICAM Definition (IDEF) Method is described. The structure and schematic representation of the IDEF0 methodology is discussed, and the diagramming methodology is explained. For a detailed discussion, the reader is referred to publications by the Integrated Computer Aided Manufacturing organization (Integrated 1981).

The Integrated Computer Aided Manufacturing (ICAM) Definition Method (IDEF) is a set of structured analysis techniques for performing system analysis. Its main purpose is to provide engineering methods for analyzing and designing complex systems, and is used to understand and manage such systems (Wallace et al. 1987). IDEF supports multiple views of the system, and allows the system to be modeled from three different perspectives: Functional, Informational, and Dynamic.

In this report, the scope of modeling is limited to process modeling techniques. Therefore, the discussion will be limited to the functional model IDEF0. The reader should keep in mind that functional modeling perspective is the first step in the IDEF modeling methodology, and informational and dynamic models may be developed in the future to create a comprehensive model of the construction process.

4.1.1 Schematic Presentation

Each box in the diagram represents a function which is an activity, action, process, operation, or a transformation (Integrated 1981). One or more inputs are transformed into one or more outputs using the mechanisms provided. The transformation process is controlled by one or more controls. Data is defined as any information or physical object which is transformed, constrains the function, or results from the function. The data entities are represented schematically in Figure 4.1.
Five entity types are used in the IDEF0 modeling methodology: function, input, output, control, and mechanism. Each is briefly described below (Integrated 1981):

**Function:** An activity, action, process, operation, or transformation which is described by an active verb and an object is a function. The function is shown by the box in the diagram.

**Input:** An input is an entity which undergoes a process or operation, and is typically transformed. It enters the left of the box, and may be any information or material resource.

**Output:** Shown exiting the right side of the box, outputs include entities, such as data, which result from a process or objects which are created by a function.

**Control:** Control elements are entities which influence or determine the process of converting inputs to outputs. Controls may limit the activity or allow the activity to occur but will not be affected by the activity itself. On the diagram, controls are shown entering the top side of the box.

**Mechanism:** Shown on the bottom side of the box, mechanisms are entities, such as a person or a machine, which perform a process or an operation. It describes how a process is accomplished.

An example is shown in Figure 4.2 which demonstrates the use of each data entity type.
4.1.2 Structure of IDEF0
IDEF0 represents a system by means of a model composed of diagrams, text, and glossary. The model is a series of diagrams with supportive documentation that divide a complex subject into its component parts (Integrated 1981). The diagrams consist of boxes and arrows which express the functional activities, data, and function/data interfaces. Text accompanies each diagram which narrates the activities in the diagram. In the glossary, all terms used in the diagrams are defined.

Hierarchy of IDEF0 Diagrams: IDEF0 starts by representing the whole system as a single box with arrow interfaces to the environment external to the system. This box is decomposed into between three to six functions, each of which may be further decomposed into subprocesses. This top-down decomposition process may be continued, generating between three to six "child" or detail diagrams for each function on any given level. A hierarchy of diagrams results, as shown in Figure 4.3.

Gradual Exposition of Detail: The number of functions in each diagram is limited to a minimum of three and maximum of six. This limits the level of detail and complexity in any diagram while preventing the diagram from being trivial. The level of detail is also controlled by the position of the diagram in the hierarchy of diagrams. Each level of decomposition increases the amount of detail, resulting in a gradual exposition of detail. Decomposition along any given node is discontinued when the level of detail is sufficient for the application of the model.
Modularity of IDEF0 Diagrams: When a box is decomposed, the scope of the function and its interface arrows create a bounded context for the subfunctions. The scope of the detail diagram fits completely inside its parent function, and the interface arrows of the parent box match the external arrows of the detail diagram. Therefore, all arrows which enter or exit the detail diagram must be the same arrows which interact with the parent diagram.

Numbering the IDEF0 Diagrams: The highest level in the model which is the single box representation of the system is labeled A-0. The next level of decomposition shows the major functions of the system and is called the A0 level. Each box in this diagram is labeled from A1 up to A6 and is ordered in sequence. Decomposition of each box leads to diagrams A1 through A6. Further decomposition leads to additional digits placed after a decimal point, so that the diagram resulting from decomposing the first function on four successive levels is represented by A1.111. This numbering system allows the user to retrace the steps of decomposition through the parent function of each diagram. The models developed in this report place the decimal after the letter, e.g., D.1.

4.1.3 Tunnelled Arrows
To maintain integrity of the model, the diagrams must remain consistent from one level to the next. All data entities which interface with a function box must appear on its detail diagram as arrows entering or leaving the boundaries of the detail diagram. Exceptions may be made, however, with arrows which are tunneled. Tunnelling indicates that the data conveyed by these arrows are not relevant to the particular level of detail. For example, all processes in the previous example in Figure 2.2 require time as a control. However, no new information is gained by showing time at each function. In such cases, it would be appropriate to show the data entity tunneled at the highest level and not show it in the following levels.

Examples of tunneled arrows are shown in Figure 2.4. Tunnelling on the connected end (e.g. C3, O1) indicates that the data entity may not be shown in lower levels of detail. Tunnelling on the unconnected end (e.g. I1, C2) represents data entities which may not be present in the higher level diagrams.
It is possible for tunneled data entities to not appear for several levels, then reappear as a tunneled arrow. To reduce confusion, such data entities should be labeled at their origin.

4.1.4 Layout of Model
The PC process model comprises a set of numbered flowcharts drawn using the IDEF0 method described, a set of definitions of the functions in the boxes and a glossary of definitions of the different information elements represented by arrows. Each drawing can be traced through its number in the title block to its origin in the parent diagram (located in the left hand lower corner of the box). The diagrams should be read first, then the supporting documents.

4.2 Reading IDEF0 Diagrams
The IDEF0 model is a series of diagrams arranged in a hierarchical manner. The model is read top-down, and the following sequence should be followed in reading it (Integrated 1981):

1. Scan the boxes in the diagram to get a general impression of what is being described.
2. Refer back to the parent diagram and note the arrow connections to the diagram. Try to identify a "most important" input, control, and output.
3. Find the central theme of the current diagram. Try to determine if there is a main path linking the "most important" input or control and the "most important" output.
4. Mentally walk through the diagram from upper left to lower right, using the main path as a guide. Study the overall content of the diagram.
5. Read the text provided to gain a further understanding of the author's intent.
4.3 The IBPM Description

This section describes the first level of the Integrated Building Process Model (IBPM). It will be used in later versions of this report to compare to the Fujita PC process model. The IBPM was developed by Sanvido (1990) to represent the processes which are performed to provide a facility. The detailed IDEF0 model for this process is described in "An Integrated Building Process Model" by Sanvido (1990). The upper level of this model is shown in figure 4.4. Descriptions of the processes in this model follow.

Manage Facility includes all the business functions and management processes required to support the provision of the facility from planning through operations. These activities focus on converting a facility idea, time and money into a facility team, documents and contracts, facility management plans, and resources to support the project. This function runs for the duration of the facility life. It is controlled by two major factors - performance information about the facility as a whole and information to optimize subprocesses within the facility e.g., constructability information. The facility champion is the key to ensure the success of this function.

Plan Facility encompasses all the functions required to define the owners needs and the methods to achieve these. These activities translate the facility idea into a program for design, a project execution plan (PEP), and a site for the facility. Major controls are constraints imposed by project participants (e.g., the owner or engineer), the facility plan, the contract and optimization information. Other outputs include facility planning knowledge and information on the performance of the team.

Design Facility comprises all the functions required to define and communicate the owner’s needs to the builders. These activities translate the program and execution plan into bid and construction documents and operations and maintenance documents that allow the facility to meet the owner’s needs. Controls or constraints include program and site information, the contract, facility planning knowledge transferred to the design team, the PEP and the design plan. Again, facility design knowledge and information on the performance of the design team is another output.

Construct Facility includes all functions required to assemble a facility so that it can be operated. These activities translate resources (e.g., materials) in accordance with the design into a completed facility. Typically appropriate facility operations and maintenance documents are generated. As a result, facility construction knowledge and information on the performance of the construction team is generated. Controls include bid and construction documents and criteria, the PEP, facility design knowledge transferred to the team, the contract and the construction plan.
Operate Facility comprises all of the activities which are required to provide the user with an operational facility. In addition, operating knowledge, and information on the performance of the team is generated. This process is controlled by the facility construction knowledge available to the team, the facility operating and maintenance documents, the PEP, the operating plans and the contract.

The next section describes the process model being developed for Fujita's precast concrete process using the IDEF0 modeling methodology.
5 PRECAST CONCRETE PROCESS MODEL

The model which follows represents the different processes which are currently being performed by the Fujita Corporation on precast concrete projects. This model was developed by visiting Koriyama Mitsubi and Misato New Town PC sites, Fujita headquarters and the Chiba PC Manufacturing Plant and through discussions with Fujita engineers, researchers, and managers. The process model was reviewed by the collaboration members at three separate phases. The process model presented is the third version and has resulted in a deeper understanding by Fujita and Penn State personnel of the whole process.

The PC tasks performed by Fujita are organized into the design, manufacturing, and construction phases of the project. The model is developed to three levels of detail. These levels are described in the following text. All the process model diagrams are contained in this section. The reader is referred to Appendix B for a full set of definitions of the terms in the model.

P. Provide PC Building
The process being modeled is the provision of a PC building. Figure 5.1 shows the different external factors which effect the provision of the PC building. There are three major phases of the PC process to be modeled at the first level (Figure 5.2). At this level we categorized the basic activities into Design PC Building; Manufacture PC Building and Construct PC Building. Each of these three major phases will now be hierarchically decomposed.
Figure 5.2: Provide Precast Concrete Building
D. **Design PC Building** (Figure 5.3)
The design of the building is the process were the form, shape and function of the building and its elements are defined. This process is contained in the process model since the PC elements make up the structure and/or the envelope of the building.

D.1. **Perform Preliminary Design** (Figure 5.4)
The preliminary design is created by performing the preliminary architectural, structural and equipment design as well as performing a preliminary estimate and schedule. The final process is to evaluate the preliminary design and to decide whether to continue the project with the design.

D.2. **Perform Architectural Design** (Figure 5.5)
During this process, the following information is created; floor plans, elevations, sections and details. This process is either performed by the Architectural Design Department in the main headquarters building or it is performed by another design company. The COMPASS architectural design program is used to create a 3D design model and the architectural design drawings if the process is performed by Fujita.

D.3. **Perform Structural Design** (Figure 5.6)
A structural analysis of the building must be performed so that the detailed locations, sizes and shapes of the members can be determined. The structural calculations are performed with BuildSYS computer program after the information is input by a structural engineer.

D.4. **Perform Equipment Design** (Figure 5.7)
The different equipment in the building must be designed. The equipment includes electrical, mechanical and fire & safety equipment. This process is performed by the Equipment Design Department in Fujita or by another company.

D.5. **Estimate Building Cost** (Figure 5.8)
The Estimating Department is responsible for producing the estimated cost all the items in the building. This is performed by doing a detailed quantity takeoff of the materials used in the building and assigning a unit cost per to the materials. Then the final price of the building is determined.
Figure 5.3: Design Precast Concrete Building
Node D1: Perform Preliminary Design

* Note: Evaluation of preliminary designs only occurs if more than one preliminary design is proposed.

Figure 5.4: Perform Preliminary Design
Figure 5.5: Perform Architectural Design
Node D5: Estimate Building Cost

Figure 5.7: Estimate Building Cost
M. Manufacture PC Building (Figure 5.9)
The manufacturing of the PC building contains all processes which are necessary to create the precast concrete elements and to deliver them to the construction site. The manufacturing process is usually performed by the members of the PC Department of Fujita and a precasting plant. Sometimes the manufacturing of the members will be performed at the construction site. In this case, all the processes will still occur, but the location and team members will be different.

M.1. Design PC Elements (Figure 5.10)
The detailed manufacturing drawings are developed during this process. This includes all drawings which are needed by the manufacturing plant in order to perform the manufacturing process.

M.2. Plan Production Method (Figure 5.11)
The location, schedule, and resource allocation for the manufacturing of the PC elements must be determined. This task is performed by the office at the PC plant. This process is very dependent on the experience of the management in the PC plant and a very small amount of documentation of this process is created.

M.3. Procure Manufacturing Materials (Figure 5.12)
The materials needed to produce the PC elements are ordered by the PC plant. One of the critical items which must be purchased is the formwork. The forms are purchased from a form manufacturer and many forms need to be specially designed for a project.

M.4. Produce Elements (Figure 5.13)
The following processes must be performed in the factory to produce the element:
- Prepare forms for concrete
- Place the concrete in the forms
- Finish and cure the concrete
- Strip and clean the forms
- Repair, clean and inspect the PC elements
- Store the PC elements
Most tasks in the Chiba PC Factory are performed manually with the assistance of equipment.
M.5. Transport Elements (Figure 5.14)
The elements are hoisted onto a truck and transported to the construction site. The truck driver must know the location of the site and the PC elements which he is to transport, so a distribution plan is created by the PC plant to communicate this information to the driver and the workers on the construction site. Bar codes are used to help identify the PC elements.
Figure 5.10: Design PC Elements

Node M1: Design PC Elements

* Other Details include tile details, framework details, etc.
Figure 5.11: Plan Production Method
Figure 5.13: Produce Elements
Figure 5.14: Transport Elements
C. Construct PC Building  (Figure 5.15)
The first step in this process is to plan the construction methods which will be used on the project. Then the erection of the PC elements begins and this process must be managed. Fujita is only responsible for managing the construction process. The actual construction of the PC elements is performed by a subcontractor. A breakdown of the elements in the process follows.

C.1. Plan Construction Process  (Figure 5.16)
The method which will be used to construct the project is designed by the management team located on the construction site. This includes the following processes:
- Develop general plan
- Create site layout
- Schedule PC sequence of erection

C.2. Manage Construction Process  (Figure 5.17)
After the construction plan is developed, the plan must be communicated to the subcontractor, monitored for problems, and revised as needed. These tasks are the responsibility of the Fujita management team on the construction site.

C.3. Erect PC Elements  (Figure 5.18)
The following processes must be performed by the subcontractors on the site to erect the PC elements:
- Place elements in structure
- Provide temporary bracing
- Plumb, level, and align
- Permanently connect elements

This concludes the presentation of the process model. From the process model, the different information elements can be extracted and these elements can be organized in a hierarchical structure. This provides a framework for the information architecture which can be used for organizing the different information elements. This information framework or information architecture is described in the next section.
Node C: Construct PC Building

Figure 5.15: Construct PC Building
Node C2: Manage Construction Process

Figure 5.17: Manage Construction Process
Figure 5.18: Erect PC Elements
6 INFORMATION ARCHITECTURE

This section defines an information architecture (IA) which can be used to categorize the different information elements contained in the PC process model. It is important to develop a structure for the different information elements in order to integrate the processes and the information flowing between the processes. The elements are categorized into four main areas: Product Information; Process Control Information; Feedback Information; and Constraint Information. The specific elements in the IA are defined in Appendix B and are defined as the information elements found on the arrows in the IDEF0 process model. The different category explanations follow.

6.1 Product Information
Product information is defined as information that is used to describe and communicate the facility in its various stages of development to those involved in the process (Sanvido, 1991). The product information elements for precast concrete are shown in Figure 6.1.

6.1.1 Design Information:
The design information defines the shape, materials and location of the PC elements in the building. This information is used for both the manufacturing and construction phases of the project.

6.1.2 Manufacturing Information:
The manufacturing information is used by the PC plant to manufacture and transport the PC elements to the site. The major component of this category is the PC element design.

6.1.3 Construction Information:
This information can be used by designers during renovation projects to the building in the future. It can also be used during the operations and maintenance of the building. There are no PC information elements in this section since there is little need for maintenance of PC elements.

6.2 Process Control Information
Process control information is defined as elements which are required to control the process of providing a facility (Sanvido 1991). Figure 6.2 and 6.3 shows the process control information
elements which are needed for the PC method. We need to obtain examples of this information to complete this description.

6.3 Feedback Information
Feedback information is defined as elements that affect the control of the overall process (Sanvido 1991). Figure 6.4 shows the feedback information elements which are needed for the PC method.

6.4 Constraint Information
Constraint information is defined as parameters or variables that hinder, limit or impact the process of providing the facility (Sanvido 1991). Figure 6.5 shows some of the constraint information elements which may affect the PC method. This information may be common for all the Fujita PC projects and may be redundant.
Figure 6.1: Product Information Elements
Figure 6.3: Process Control Information Elements (Page 2 of 2)
Figure 6.4: Feedback Information Elements

- Title
- Subcategories
- Level 0
- Level 1 (Provide PC Building)
- Level 2 (Design, Manuf., or Consr)
- Level 3

- Feedback Information
- Performance Information
- Optimization Information
- Construction Feedback
- Constructability Information
- Design Feedback
- Structural Feedback
- Equipment Feedback
- Cost Feedback

- Preliminary Design Feedback
  - Preliminary Structural Feedback
  - Preliminary Equipment Feedback
  - Cost & Schedule Feedback

Legend:
- Dashed line: One of the elements
- Solid line: A full decomposition of the elements

Figure 6.4: Feedback information Elements
Figure 6.5: Constraint Information Elements
7 DISCUSSION

This section reflects on the PC process at Fujita as represented by the process and information models earlier in this report. The process model is compared to the Integrated Building Process Model developed by Sanvido (1990) presented in section 4. By comparing these two models, differences between the processes can be identified. After this comparison, areas for future research are presented.

The two models contain some differences due to the assumptions which were used in developing the precast concrete process model. The PC process model assumes that the architectural programming or planning phase in complete, and the operation of the facility is not within the scope of work. Comments are thus confined to manage, design and construct phases.

Key observations derived from comparing the models are:
- Both design and construction nodes are essentially similar.
- Construction management practise in Japan and the US are similar in scope of work.
- The IBPM does not consider the manufacturing process as part of the life cycle of a facility.
- The essential information elements are similar to both models.
- Resource acquisition is a large part of both processes.
- Feedback on costs are more explicit in the IBPM.
- Schedule feedback is essentially similar in both cases.
- Design steps and disciplines are very similar.

Based on our discussions with Fujita employees, comparisons of the models and the site observations we believe that the areas requiring further research include:

1. Exploring the role of contractual relationships between the owner and design/construction and their impact on mangerial practise. Before developing software, we believe that a method must be developed to classify and control the flow of information through the various processes over the life of a precast element to facilitate integration.

2. Developing methods and tools to provide a single perspective for the management of the overall process from design through manufacturing to construction. A top down information structure should be developed for the entire process, and prototype software should be developed to illustrate the rules and information required to support the
management of the design, manufacturing, and construction processes. This will set the framework for linking existing software and managing the data flows between them.

3 Develop a simulation method to accurately conduct analysis of the impact of scheduling the design, manufacturing and construction of the PC facility during the planning phase. By developing a simulation model, Fujita will be able to anticipate the possible difficulties that may occur in the manufacturing and construction phases of a PC building. The plan should be able to develop a preliminary plan for the process with a limited amount of parametric data. The plan should include:

- Preliminary design, manufacturing and construction schedules
- Preliminary design, manufacturing and construction estimates
- Preliminary manpower and resource demands

This report has provided an overview of the processes used by Fujita in constructing PC buildings. It serves as a framework for common understanding and research by both organizations. The next step is to develop and flesh out goals for further research and development. This should be accomplished through mutual discussion.
Appendix A

BIBLIOGRAPHY


FUJITA DOCUMENTS


Fujita, Fujita's Prefabrication System for Concrete Buildings, 1983.


Fujita, PC Method.


Appendix B

GLOSSARY OF TERMS

Architectural Design Team: All parties which are responsible for developing the Architectural Design for the precast concrete building.

Architectural Design: This contains information on the layout of the space and the sizes and materials for the different spaces in the building.

Architectural Floor Plans: The drawings which contain information about the layout of space, materials used and exact dimensions for the building.

Available Resources: The personnel, computer technology, time, space, equipment, materials, energy, funds, etc., available to the project.

Building Estimate: The cost estimate for all the elements in the building plus overhead and additional charges to the owner.

"BuildSYS" Program Inputs: An input file which contains an interpretation of the architectural design and preliminary structural design. The "BuildSYS" program will interpret this input information and determine whether the preliminary sizes are adequate.

Concrete Filled Form: This is the form with everything in it, including the wet (freshly placed) concrete.

Constructability Information: The information used to integrate the construction experience on the project into the earlier design phases to optimize the provision of the precast concrete building.

Construction Labor: All construction field employees who are involved in the erection of the precast concrete elements.

Construction Directives: Instructions and advise which are provided from the site management team which assist the subcontractor in the erection of the precast concrete elements.
**Construction Equipment:** All equipment on the construction site which is used during the erection and connection of the precast concrete elements.

**Construction Feedback:** Information from the construction field employees which is used to alter the construction plan and to keep a historical record of the construction project.

**Construction Plan:** A working document including the methods plan, estimate, schedule, material take-off, etc. that defines the goals and means for the construction of the building.

**Construction Resources:** The personnel, computer technology, time, space, equipment, materials, energy, funds, etc., available for the "Construct PC Building" process.

**Construction Team:** All parties who will participate in the construction of the building.

**Cost Database:** A computerized database which contains historical cost information about projects which Fujita has constructed.

**Cost Feedback:** Feedback information from the estimated cost of the building. This is used by the designers to alter the design so that the cost is closer to the projected budget of the building.

**Cured PC Element:** This is the form and all of its contents after the concrete has cured to gain sufficient strength for movement.

**Design Feedback:** Feedback from the preliminary schedule, preliminary estimate, structural design and equipment design which is used to update and revise the architectural design.

**Design Resources:** The personnel, computer technology, time, space, equipment, materials, energy, funds, etc., available for the "Design PC Building" process.

**Design Specifications:** Written information and specifications about the different elements and construction techniques which must be used in the building.

**Design Team:** All parties who will participate in the design of the building.

**Detailed Design:** The fully engineered design that is used to prepare for manufacturing and construction of the building.
**Distribution Plan:** A plan for the dates and locations of the elements which must be transported to the project site.

**Element Drawings:** Detailed drawing which show the exact sizes and locations of the different materials used to construct the precast concrete elements.

**Element Layout Drawings:** Drawings which show the locations of the joints for the precast concrete elements. It will also show the element numbers, locations and overall sizes.

**Elevations:** The drawings which contain information about the exterior and interior vertical surfaces.

**Equipment Design Team:** All parties which are responsible for developing the Equipment Design for the precast concrete building.

**Equipment Design:** This contains exact sizes and models for the mechanical, electrical and fire and safety equipment in the building.

**Equipment Drawings:** Drawings which specify the location and sizes of the different pieces of equipment.

**Equipment Feedback:** Equipment design information which is used by the architectural and structural designers. This contains exact sizes and proposed locations for the equipment in the building.

**Equipment List:** A written list of the equipment manufacturer and model numbers for the different pieces of equipment in the building.

**Equipment Loads:** The calculated equipment loading conditions for the different types of equipment.

**Equipment Specifications:** Written specifications which describe the performance requirements and sizes of different equipment in a building.

**Erected PC Building:** The physical building which is the result of the "Provide Precast Concrete Building" process.
**Estimating Department:** The department in Fujita which is responsible for producing the building cost estimate.

**Site Management Team:** All parties who are responsible for the management of the work performed on the construction site.

**Final Equipment Locations:** The exact location of mechanical, electrical, and fire and safety equipment.

**Finished PC Elements:** The cured precast concrete element after the forms have been stripped and the element has been cleaned, repaired and inspected.

**Forms with Rebar and Imbeds:** This is the form with all of the reinforcing bars, mechanical and electrical imbeds, tiles, etc. which is ready for concrete to be place.

**Forms:** Temporary molds which are used to shape the fluid concrete when building precast concrete elements.

**General Plan:** A plan which contains the methods which will be used in constructing a building project.

**Hoisted Elements:** The precast concrete elements after they are hoisted into position.

**Braced Elements:** The precast concrete elements after they have been braced with temporary bracing.

**Permanently Positioned Elements:** The precast concrete elements after they have been plumbed, leveled, and aligned.

**Joint Detail Drawings:** Drawings which show the exact sizes, locations and materials used to create the joints between the precast concrete elements.

**Legal Restrictions:** Constraints set by the government which will influence the design, manufacturing and construction of the precast concrete building.
**Loaded Elements:** Precast concrete elements after they have been loaded onto a vehicle for transportation.

**Location of Production:** The location where the precast concrete elements will be produced. This is either on the construction site, Chiba PC Factory or another precasting factory.

**Manufacturing Labor:** All employees who perform the production processes for the precast concrete elements.

**Manufacturing Equipment:** All equipment which is needed during the manufacturing process. This includes rebar cutting machines, concrete buckets, cranes, concrete vibrators, etc.

**Manufacturing Management:** The management employees who are responsible for manufacturing the precast concrete elements.

**Manufacturing Materials:** The physical materials which are used to manufacture the precast concrete elements. This includes both temporary materials (forms, cranes, etc.) and permanent materials (rebar, concrete, etc.)

**Manufacturing Plan:** The information which is used by the manufacturing team which describes how and where the elements will be produced.

**Manufacturing Resources:** The personnel, computer technology, time, space, equipment, materials, energy, funds, etc., available for the "Manufacture PC Building" process.

**Manufacturing Team:** All parties who will participate in the manufacturing of the precast concrete elements for the building. This could either be the employees of a precast concrete plant or employees used at the site for on site PC.

**Member Sizes:** This is the information about the sizes of the structural members in the building.

**Other Details:** Additional details which are needed to create the precast concrete element. These include tile details, granite details, etc.

**Owner's Requirements:** Constraints set by the owner's organization and are subject to owner's influence such as owner's strategic and operations plans.
**PC Element Design:** The detailed information used for producing a precast concrete element. This includes plan, elevation and sectional views of the precast element.

**PC Elements on Site:** The physical precast concrete elements after they have been transported to the construction site.

**PC Elements:** The physical elements which are contained in the precast concrete building. These elements are created in the manufacturing process.

**PC Estimate:** A detailed estimate of the cost for manufacturing the precast concrete elements.

**PC Manufacturing Limitations:** The limitations of the manufacturing area which constrain the quantity and quality of the manufactured elements.

**PC Schedule:** The schedule created by the construction team which describes when each precast concrete element will be erected into the structure.

**PC Team:** All members who are responsible for the design, manufacturing and construction of the precast concrete building.

**Permanent Material Orders / Contracts:** The documents and agreements with material vendors for the purchasing of the permanent materials which will eventually be used in the produced precast concrete element.

**Precast Concrete Department:** The department in Fujita which is responsible for the precast concrete element design, budget and schedule.

**Preliminary Architectural Design:** This contains preliminary information on the layout of the space, elevations, 3-D model, etc. for the building.

**Preliminary Design:** The initial design which contains form and function information for the building.

**Preliminary Equipment Design:** This constrains preliminary types, sizes and loads for the mechanical, electrical and fire and safety equipment in the building.
**Preliminary Estimate:** The preliminary cost estimate for all elements in the building, plus overhead and additional charges to the owner.

**Preliminary Locations:** An estimate on the location of mechanical, electrical, and fire and safety equipment.

**Preliminary Schedule:** The preliminary information on design and construction times for the project. It also contains key deadlines for the project.

**Preliminary Structural Design:** This constrains preliminary type, layout and sizes for the structural elements.

**Production Layout:** The location in the precast concrete factory or on the site where the element will be produced.

**Production Schedule:** A schedule of the activities for producing each element.

**Production Summary Schedule:** A schedule which contains information of when the different precast concrete elements will be produced.

**Project Planning Team:** All parties who are responsible for performing the preliminary design process.

**Quantity Takeoffs:** The quantities of each specific material type in a building.

**Resource Allocation Plan:** A plan which contains the quantities and required dates for the different materials needed to produce the precast concrete elements.

**Sections & Details:** Drawings and information which give information about sections through a specific area of the building or which provide more detailed information about an area of the building.

**Site Layout:** A document which show the locations and flows of the different temporary and permanent materials and equipment which is needed during the construction process.
Structural Design Team: All parties which are responsible for developing the Structural Design for the precast concrete building.

Structural Design: This constrains exact sizes for the structural elements and detailed calculations to justify the element sizes.

Structural Feedback: Feedback information which will alter the member sizes of the building. The structural feedback contains updated proposed sizes for structural elements which must be structurally evaluated.

Structural Feedback: Structural information which is used by the architectural designers. This contains exact sizes and locations of structural members.

Structural Analysis: This is numerical information which describes the sizes and locations of the structural elements in the building. This information also contains the structural analysis calculations which are required by the Japanese building codes.

Subcontractors: Companies which are employed by Fujita to perform the construction activities on the site.

Temporary Material Orders / Contracts: The documents and agreement with vendors for the purchasing or rental of materials and equipment which will be used during the production of the precast concrete elements but will not become part of the final element.

Transported Elements: The precast concrete elements after they have been transported to the site but before they are hoisted from the transportation vehicle.

Transportation Subcontractor: A subcontractor which is hired by Fujita or the precast plant who is responsible for the transportation of the elements from the plant to the project site.

Transportation Team: All parties who will participate in the transportation of the precast concrete elements from the manufacturing area to the construction site.

Unit Prices: Prices per unit for each of the materials and for each type of labor required to construct the different elements in the building.