CONCEPTUAL MODELS FOR PLANNING OF BUILDING AND CONSTRUCTION SYSTEMS

Yusuke Yamazaki
Manager
Intelligent Engineering Systems Department
Technology Division
Shimizu Corporation
No.1-2-3, Shibaura, Minato-Ku, Tokyo 105-07, Japan

Abstract

Presently, Computer Integrated Construction (CIC) is recognized as a strategy as well as a concept for associating existing resources, technologies, processes and organizations by information integration and automaton to optimize overall construction activities and functions. However although innovative computer and automation applications to the Architectural/ Engineering/ Construction (A/E/C) industry are introduced, no efficient approach to implement a full scale CIC has been established. Several attempts have taken place in different areas of the A/E/C industry depending on specific business characteristics, which also indicate potential applications of product modeling, process modeling and information modeling to a practical approach to the total CIC. The aim of this paper is to present results of current research and development issues on conceptual models which enable interactive planning between design and construction planning focusing on building systems and construction systems.Several types of conceptual models are efficiently applied to explore distributed project planning and management in several planning stages. These models also incorporate conceptual product models represented as building system models, and conceptual process models represented as construction system planning models, construction activity planning models and construction facility planning models for CIC.

Key words
conceptual model; building system; construction system; CIC; knowledge processing

Introduction

Recently , innovative and sophisticated applications of industrialized and integrated building systems, automated construction systems, and information systems based on information and knowledge integration have been introduced to the field of building construction. These components are to be further functionally integrated to prototype CIC system, which will cause organizational and structural innovation A/E/C industry.

Among the construction technologies in A/E/C industry, building systems and construction systems have been developed and improved by adopting new structural systems, new materials, automated facilities and computers. Since efficient applications of newly developed and improved building system and construction systems require complex and variety of problem solving in design , construction planning and management stage, organizational and comprehensive investigations by specialists in various domain are necessary. Therefore, information and knowledge to perform a comprehensive investigation are viewed as challenging resources to reduce the complexity and fragmentation of design and construction processes by utilizing innovative computer technologies, such as knowledge-based systems, database management systems, hypermedia systems and network systems.

Consequently, a prototype of integrated design and construction planning system with following components are developed: 1) knowledge-based systems to effectively solve ill-structured problems in design, planning and management process, 2) database management systems adopted to systematically store structured project information 3) multimedia system to improve user interfaces especially in reference functions, and 4) network systems to efficiently communicate among distributed database, thus optimal utilization of various information technology and knowledge engineering technologies are important.

To efficiently realize integrated system among design, engineering and construction planning, an innovative methodology for representation and utilization of building construction knowledge, a framework for knowledge acquisition and management, and a system architecture for cooperative utilization of knowledge and information of building systems and construction systems are relevant.

The main objective of this paper is as follows: 1) to describe an approach to establish CIC for the improvement of design, construction planning and management productivity focusing on building systems and construction systems, 2) to explain frameworks for conceptual models of knowledge processing on an interactive building system and construction system planning which enable concurrent design and construction planning from the beginning of project planning stage to management stage , and 3) to propose a planning and management methodology of conceptual models which also allow hierarchical management of project information and constraints.

Conceptual Modeling Approaches to CIC

According to the sophistication in applications of computer and information technology in construction industry, management of knowledge and information are viewed as major resources to efficiently utilize CIC systems. Current approaches are to structure knowledge and information with regard to the integration of design and construction to establish more efficient process and organization among design, planning and management. To structure a systematic approach to CIC, it is important to use an appropriate modeling technique. These modeling techniques can be most usefully viewed as a structured way to develop CIC.

At conceptual stage, the CIC model is divided into four major components: 1) Integrated design and construction planning system, 2) factory automation system, 3) site automation and management system, and 4) unified project database and information management system. These components should communicate and be linked by product models, process models and logistics models to establish an effective interface system among them [Yamazaki 92].

Current integration efforts are taken in both top-down and bottom-up approaches. The aim of top-down approach is to systematize design and construction planning process at first. The approach depends on extensive utilization of information technology to improve capability in construction engineering and efficiency in product design.

On the other hand, the aim of bottom-up approach is to systematize construction process including procurement, transpiration, and site fabrication of building components and materials at first. Most of these approaches depend on automation technology to improve productivity in construction activities.

To effectively establish CIC components, both approaches should concurrently performed to review functionalities subsystems in CIC components. Although comprehensive integration has not been established yet, several approaches have been setting up at component level to systematize major functions in CIC [Björk 89], [Ito 90] , [Luiten 91], [Frose 92].

Integrated Building system and Construction System Planning

Building system planning and construction system planning are particular process of product design in building construction, and is viewed as an interface of design development and construction planning.

Building system planning has been considered to be a part of design process and is to be performed through designer's responsibility. Recently industrialized and integrated building systems have been introduced to building construction, which require interactive building system planning and construction system planning as an interface of design development and construction planing. Also automated construction systems have been developed and applied in an actual construction project, which require integrated investigation of constructability of the project and performance of highly automated construction facilities.

The objective of building system planning is: 1) to specify functional requirements by building spaces depending on design perspectives, 2) to develop building subsystems and building components, and 3) to precisely define functional requirement of building subsystems and building components.

On the other hand, the objective of construction system planning is: 1) to define construction process and construction methods for building subsystems and building components based on requirements and constraints, 2) to review the building system through the investigation of constructability, and 3) to propose alterative combinations of building system and construction system and to modify the project planning perspectives on design and construction planning. Usually building system planning is evaluated and sophisticated through construction system planning, then conceptual objects of design is changed into objects for construction.

Integrated building system and construction system planning aim to perform a type of construction simulation conducted to find an optimum combination of building system and construction system, associated with construction activities and temporary facilities. To make optimal use of resources including technology and organizations, a system architecture which support an integrated investigation by designers, engineers and project managers at the early design and construction planning stage is necessary. This cooperative planning process is defined as an integrated building system and construction system planning which incorporates all levels of the project planning process, as shown in Figure 1.

To realize the requirements for the integrated construction planning system, knowledge processing issues such as structures, functions and goals of planning, knowledge for planning procedure and planning procedural knowledge modules and constraint management module, and databases which store planning status and project initial information must be structured and represented.

Knowledge Representation Process in Conceptual Planning Models

Knowledge representation process to systematize integrated building system and construction system planning is divided into the following steps:

1) Classification of characteristics and constraints of domain
2) Collection of information with characteristics and constraints
3) Representation of rules through logical analysis of collected information
4) Representation of planning functions
5) Representation of planning objects using hierarchical network of object-models
6) Representation of planning processes as classified general planning models
7) Representation of constraint management methodology

(Planning Object Model)

Building Space Model

Building
structure
specific floor
under ground
standard floor
EV corder 1st top floor
hall floor floor
2nd Nth
floor floor

Building System Model

building component
super-structure
floor block 1 block 2 block j column
block 1 beam beam
slab beam1 beam2
slab1 slab2

Construction System Model

Concreting
(V.H Separate)
Form Work
(Half PC)
pour concrete
Re-bar set
(Meshed Bar) PC panel
set concrete
welding mesh
bar fixer erector material
crane A working team
temporary facility
Resource use

Knowledge with Planning Objects

Knowledge with Planning Procedures

Cost constraint (Total budget)
Time constraint (Construction period)
Planning Scope Space constraint (Type of building, Soil condition)
Resource constraint (Availability of labor)

Knowledge with Characteristics and Constraint of Building System and Construction System

Planning Strategy
: Labor reduction
: industrialization rate
: Construction period reduction
: Total building system

Planning Assumptions

Selection of
Building System
Model

Building system S R C rigid frame
Building components
Frame model
Slab model topologies
Connections

Building system Planning

Selection of General
Building System
Planning Model

Constraints by Building System
Constraints by Construction System
Requirements by Planning Scope

Design of Building System
associated with Construction System

Construction System Planning

elemental construction system
activities Half PC
process work relations
labor
temporary facilities
materials

(Planning Process Model)

-Extension of Planning Scope
-Difinition of Goals
-Management of Planning Information
-Knowledge Processing in Planning Process

Selection of
Construction
System Model

Selection of
General Construction
System Model

Knowledge with Selection of Design and Planning Methodology
Based on Requirements and Constraints

(General Planning Model)

general building system model

Planning Model Base

Availability of Planning model
Encities
Design Method
Standard building component
column floor beam joist wall
combined model
of frame system
and slab system

general building system model

Availability of Planning model
Entity
Design method
Available construction method
Graphic representation method

construction system model

Availability of Planning model
Entity
Planning method
Construction Method Rebar From concrete
Order of activities Assembling Installation
Attributes Resources Relations
of activity Productivity

P C R C
Building system
planning model1

HPC Rigid Frame
SRC Rigid Frame
PC RC Rigid Frame

PC
Column

Half PC
PC
RC

RC-Floor Building
System
Planning model1

RC-Floor
Construction System
Planning model3
RC-Floor
Construction System
Planning model2
RC-Floor
Construction System
Planning model1

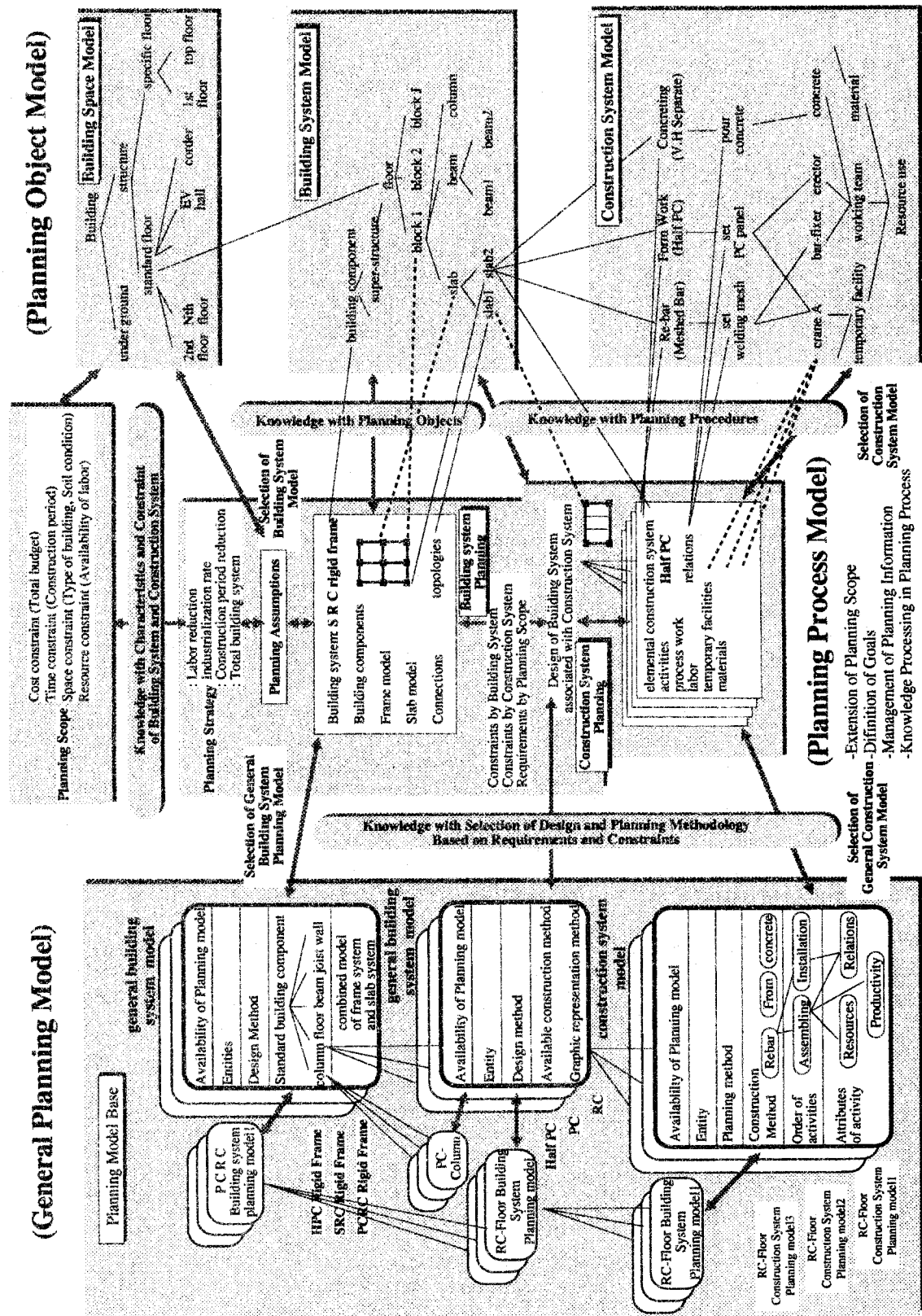RC-Floor Building
System
Planning model1

Figure.1 A Conceptual View of Planning Expansion by Conceptual Models

Depending on difference in objectives of planning phase, knowledge representation schema are strategically applied in each level of planning models. For instance, conceptual scheduling, fundamental scheduling and detail scheduling require different levels of knowledge. The objective of conceptual scheduling is to identify project constraints, to evaluate the given construction period based on building system, construction system and temporary facility planning, to produce a rough milestones to negotiate with clients and designers. Planning knowledge for conceptual scheduling is usually acquired through analysis of hundreds of actual results, and structured as a form of formula. Since the planning variables in formula is to be frequently tested and modified according to the changes in construction conditions, such as availability of labor, materials and facilities, lead time of building components, and adoptability of technology, the structure of formula should be rigid and be understandable for planner.

On the other hand, the objective of detail scheduling such as work scheduling is to define a series of activities associated with required resources, productivity and sequence to efficiently utilize resources. Major planning knowledge for detail schedule is represented as networked objects defined by building system and construction system.Thus knowledge for an integrated constructing planning is classified and represented as planning models.

Conceptual Models for Planning Objects and Planning Process

To explore distributed planning, object-oriented planning models are effectively applied to describe the interactive planning process, which incorporates building system planning, construction system planning, construction activity planning (scheduling) and construction site layout planning. Project information management module is also consists of initial project information, design information and project planning information, according to progress of planning through conceptual stage, intermediate stage, and practical stage. The project planning information is consists of combinations of domain specific planning models, which also hierarchically stored. Since these planning models relate and communicate interactively with each other, object-oriented approach is effectively applied.

To systematize interactive planning process of integrated construction system planning, functions, structure, goals, behaviors and knowledge to explore hierarchical construction must be structured and represented as object-oriented planning models. Planning models are classified into two categories. One is general planning model which is independent on project characteristics and is formalized by general planning objects, planning procedures and knowledge to explore the planning extracted from actual planning cases.The model illustrate general framework of planning and are hierarchically classified according to planning characteristics. When the planning model is applied to a project planning, project specific planning models are instantiated depending on project initial conditions and constraints.

The other one is project specific planning model which inherits attributes, functions (methods) of general planning model. When the initial conditions of project are not well defined, planning objects are to be instantiated as a similar context of general planning model. When the project specifications are well defined, detail levels of planning objects are instantiated in a form of networked object-models at each design and planning level (Figure 2).

Since planning models are to be hierarchically instantiated, planning objects must be structured and be flexibly instantiated according to the planning expansion. The planning models inherit networked planning objects and topologies among planning objects, which are defined in general planning models. A concept to expand an interactive planning between building system planning and construction system planning applying hierarchical planning process models of building systems and construction systems are also illustrated in Figure 1.
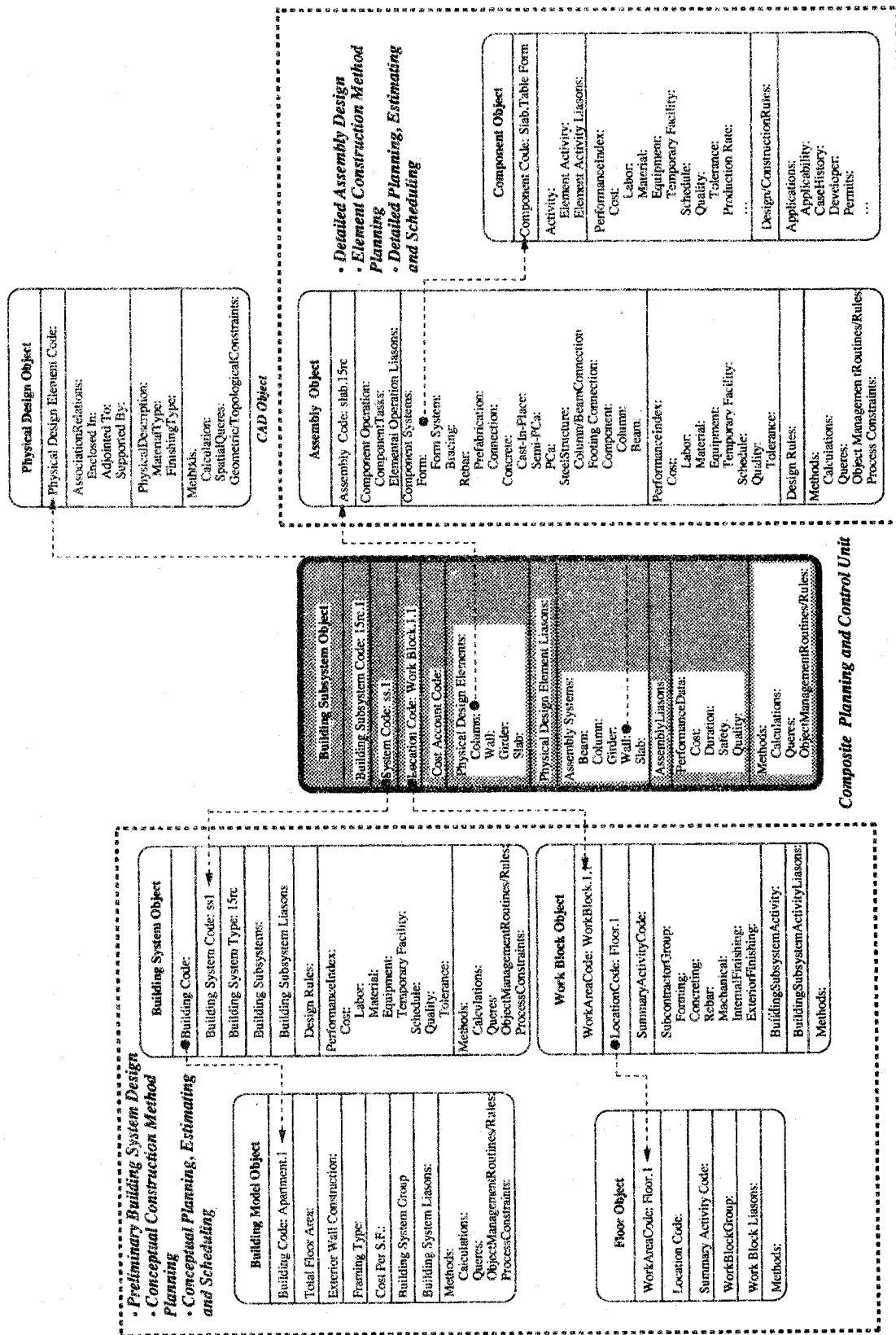
Physical Design Object

Physical Design Element Code:

AssociationRelations:
  Enclosed In:
  Adjointed To:
  Supported By:

PhysicalDescription:
  MaterialType:
  FinishingType:

Methods:
  Calculation:
  SpatialQueres:
  Geometric/TopologicalConstraints:

CAD Object

Assembly Object

Assembly Code: slab.15rc

Component Operation:
  ComponentTasks:
  Elemental Operation Liasons:
Component Systems:
  Form:
    Form System:
    Bracing:
  Rebar:
    Prefabrication:
    Connection:
  Concrete:
    Cast-In-Place:
    Semi-PCa:
    PCa:
  SteelStructure:
    Column/BeamConnection
  Footing Connection:
    Component:
      Column:
      Beam:

PerformanceIndex:
  Cost:
    Labor:
    Material:
    Equipment:
    Temporary Facility:
  Schedule:
  Quality:
  Tolerance:

Design Rules:

Methods:
  Calculations:
  Queres:
  Object Managemen tRoutines/Rules:
  Process Constraints:

Component Object

Component Code: Slab.Table Form

Activity:
  Element Activity:
  Element Activity Liasons:
PerformanceIndex:
  Cost:
    Labor:
    Material:
    Equipment:
    Temporary Facility:
  Schedule:
  Quality:
    Tolerance:
    Production Rate:

Design/ConstructionRules:
  Applications:
    Applicability:
    CaseHistory:
    Developer:
    Permits:

• Detailed Assembly Design
• Element Construction Method
* Planning*
• Detailed Planning, Estimating
* and Scheduling*

Composite Planning and Control Unit

Building Subsystem Object

Building Subsystem Code: 15rc.1

Subsystem Code: ss.1

Location Code: Work Block.1.1

Cost Account Code:

Physical Design Elements:
  Column:
  Wall:
  Girder:
  Slab:

Physical Design Element Liasons:

Assembly Systems:
  Beam:
  Column:
  Girder:
  Wall:
  Slab:

AssemblyLiasons:

PerformanceData:
  Cost:
  Duration:
  Safety:
  Quality:

Methods:
  Calculations:
  Queres:
  ObjectManagementRoutines/Rules:

• Preliminary Building System Design
• Conceptual Construction Method
* Planning*
• Conceptual Planning, Estimating
* and Scheduling*

Building System Object

Building Code:

Building System Code: ss1

Building System Type: 15rc

Building Subsystems:

Building Subsystem Liasons:

Design Rules:

PerformanceIndex:
  Cost:
    Labor:
    Material:
    Equipment:
    Temporary Facility:
  Schedule:
  Quality:
  Tolerance:

Methods:
  Calculations:
  Queres:
  ObjectManagementRoutines/Rules:
  ProcessConstraints:

Building Model Object

Building Code: Apartment.1

Total Floor Area:

Exterior Wall Construction:

Framing Type:

Cost Per S.F.:

Building System Group:

Building System Liasons:

Methods:
  Calculations:
  Queres:
  ObjectManagementRoutines/Rules:
  ProcessConstraints:

Work Block Object

WorkAreaCode: WorkBlock.1.1

LocationCode: Floor.1

SummaryActivityCode:

SubcontractorGroup:
  Forming:
  Concreting:
  Rebar:
  Mechanical:
  InternalFinishing:
  ExteriorFinishing:

BuildingSubsystemActivity:

BuildingSubsystemActivityLiasons:

Methods:

Floor Object

WorkAreaCode: Floor.1

Location Code:

Summary Activity Code:

WorkBlockGroup:

Work Block Liasons:

Methods:

Figure.2 Planning Objects for Building and Construction System Planning

An Object-Oriented Approach to Knowledge Modeling

To apply object-oriented approaches to an interactive building system planning and construction system planning, two types of knowledge representation approaches were investigated and implemented as prototypes:

1) Components of building system such as columns, beams, walls and floors and Components of construction system such as construction method and facilities for formwork, steelwork and concrete work are defined as fundamental planning objects, in which attributes such as specifications of components, topologies for connections and methods to decide divisions of each building components and building elements, selection of construction methods and investigation of construction procedures are defined. These planning objects communicate each other via planning black board by message passing until whole planning objects for a building system and related construction systems are instantiated and decided.

2) In contrast with the former approach, planning objects do not contain functions to explore interactive planning, but involves structured network of objects for planning, which are to be expanded in planning process models which contain planning procedural knowledge and functions to perform interactive planning among different planning components. These planning process models control instantiations and management of planning objects based on methods inherited from general planning models.

When a domain to be solved is well-defined and requires domain specific knowledge much more than that of general planning area, this approach is useful, however it is not so efficient in managing consistency in exploring interactive planning. Since the integrated construction planning is comprehensive, flexible, opportunistic, and transparent in planning expansion process, the latter approach has been taken to systematize integrated construction planning process, especially in describing building system planning and construction system planning.

A Constraint Management Methodology by intermediate Planning Objects

Two types of management methodologies to manage consistency in hierarchical planning among building system planning, construction system planning, construction activity planning, construction facility planning and site layout planning are investigated. One is to control by system architecture, such as version management based on computer technology. The other is to control by a planner through evaluation of the planning by intermediate planning objects such as industrialization rate in building system, construction period reduction rate defined by construction systems, and labor reduction rate based on construction methods applying construction management technology. These intermediate planning objects are utilized to both evaluation of the planning and to set up a scope to develop the planning. To simplify the control of planning expansion process, the method to utilize intermediate planning objects is applied to systematize constraint management in preliminary design and construction planning stages, shown in figure.3. The constraint management module is involved in planning scope development module in integrated building system and construction system planning to assist planners to efficiently perform hierarchical and integrated construction planning.

Conclusions

The system architecture has been designed and object-oriented planning models have been developed. Further research and implementation issues will focus on development of hierarchical and interactive knowledge-based planning process among building system planning and construction system planning and constraint management.

Essentially building system planning is to be explored based on design methodology, and construction system planning is to be expanded based on construction planning methodology. Since major knowledge required to efficiently apply innovative building systems and construction systems to actual projects should be acquired and represented through investigations and experiments in technology development stage, efficient conceptual modeling methodology should be established through analysis, classification, generalization and standardization of interactive design and construction planning process in several planning phases, depending on characteristics and constraints of building systems and construction systems.
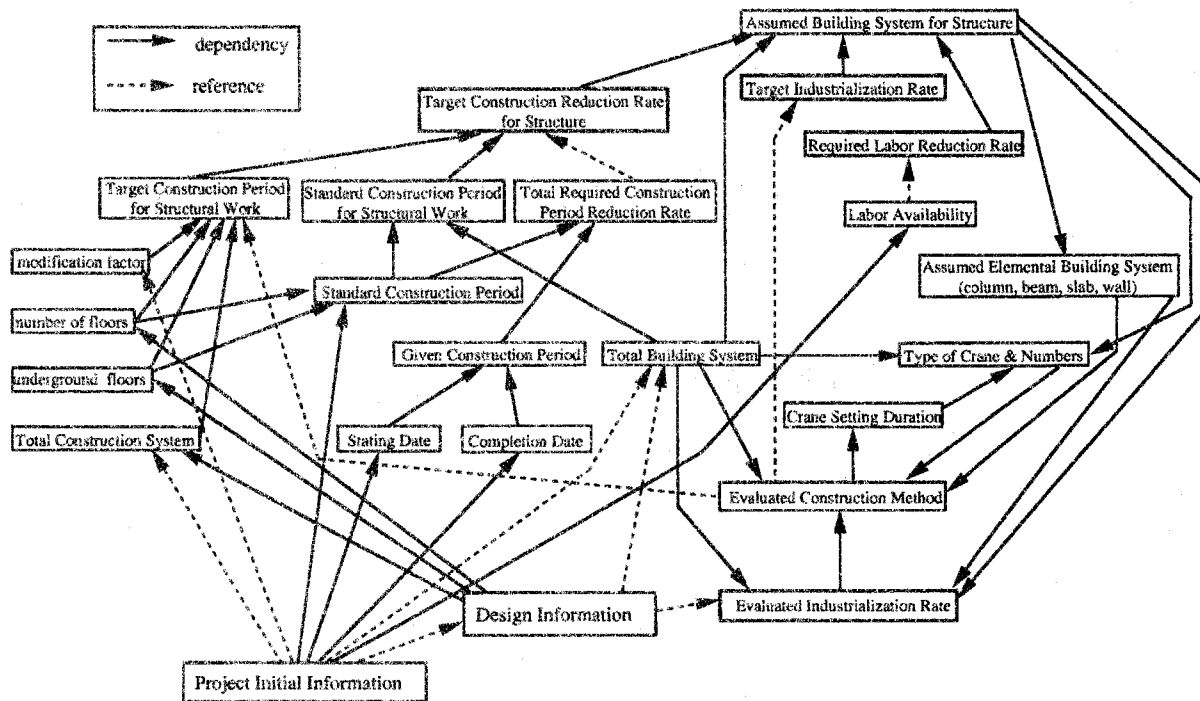

Figure 3. Constraint Management Methodology By Intermediate Planning Object

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