A FRAMEWORK OF INTEGRATING DESIGN AND PRODUCTION SYSTEM FOR THE OFF-SITE BUILDING PRODUCT INDUSTRY

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The UK construction industry is going through a major re-appraisal with the objective of reducing construction cost by at least 30% by the end of this millennium. Prefabrication and off-site construction are set to play a major role in improving construction productivity, reducing cost and improving working conditions. In a survey of current practices of the prefabrication industry by the author, it was concluded that the industry is far behind other manufacturing-based industries in terms of the utilization of IT in production planning and scheduling and other technical and managerial operations. It is suggested that some form of systematic approach to presenting and processing information is needed, using an integrated computer-aided approach. The objective of this research is to develop an integrated intelligent computer-based design and production system for the precast concrete industry. The system should facilitate; the integration of design and manufacturing operations; automation of generating production schedules directly from design data and factory attributes and generation of erection schedules from site information, factory attributes and design data. It is hypothesised that the introduction of such a system would reduce the total cost of pre-casting by 10% and encourage clients to choose the precast solution.

Keywords: integration, scheduling, pre-casting.

INTRODUCTION

Pre-casting is the process of producing building products and components, mainly concrete products, in a factory-based environment. It offers the greatest potential for radical improvement of productivity and quality in building. The research is focused on the make-to-order manufacturing environment where standard and non-standard products are produced to a particular client with unique specification orders and requirements.

A factory production environment usually provides higher technological efficiency, better working conditions and more rigorously enforced quality control (Retik, et al 1995). A building component, which can be prefabricated and then assembled on site, promises a better performance and a more economic use of resources than when constructed on site. It has been argued that activities on site should be reduced to a bare minimum and off-site manufacturing should be increased (Powell 1995). In a manufacturing environment, the application of IT has had a substantial impact on almost all activities in a factory. Often, the introduction of computers in the work place has changed the organizational structure of a factory and made necessary the adaptation of a completely different and new management structure.

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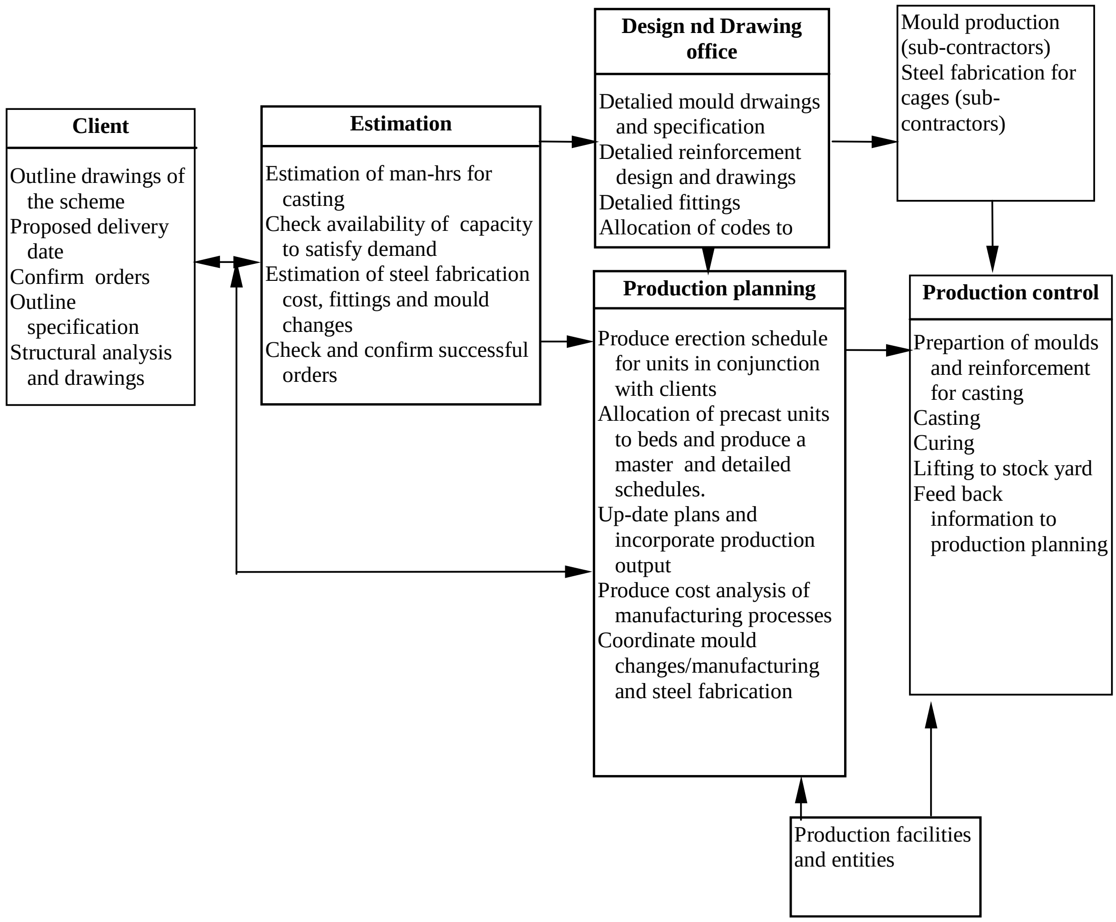

Figure 1: Business process flow chart

The development of the integrated framework has been proceeded by a compreh-ensive industrial review. Current practices of twelve major companies (makes about 90% of pre-cast volume in the UK) have been studied and evaluated using semi-structured interview with managers within the organizations and case studies. Figure 1 shows a generic model for current practices and 90% of the companies follow such a model.

In a survey of current managerial practices, it was concluded that:

- Managerial practices and in particular planning are fairly basic, manually driven and may be inaccurate.
- Communications inside a factory are often primitive and some form of IT application has the potential to bring the industry into the 21st century.
- Detailed design, capacity planning, production scheduling and erection schedules are fragmented and manually driven. This is causing extra financial burden on the industry and depriving it from substantial growth. The need for a coherent manufacturing information system is quite apparent.
- Designers may have no appreciation of downstream operations, which include production, transportation and erection. This has caused extra burden on the industry resulting from inefficient utilisation of moulds.

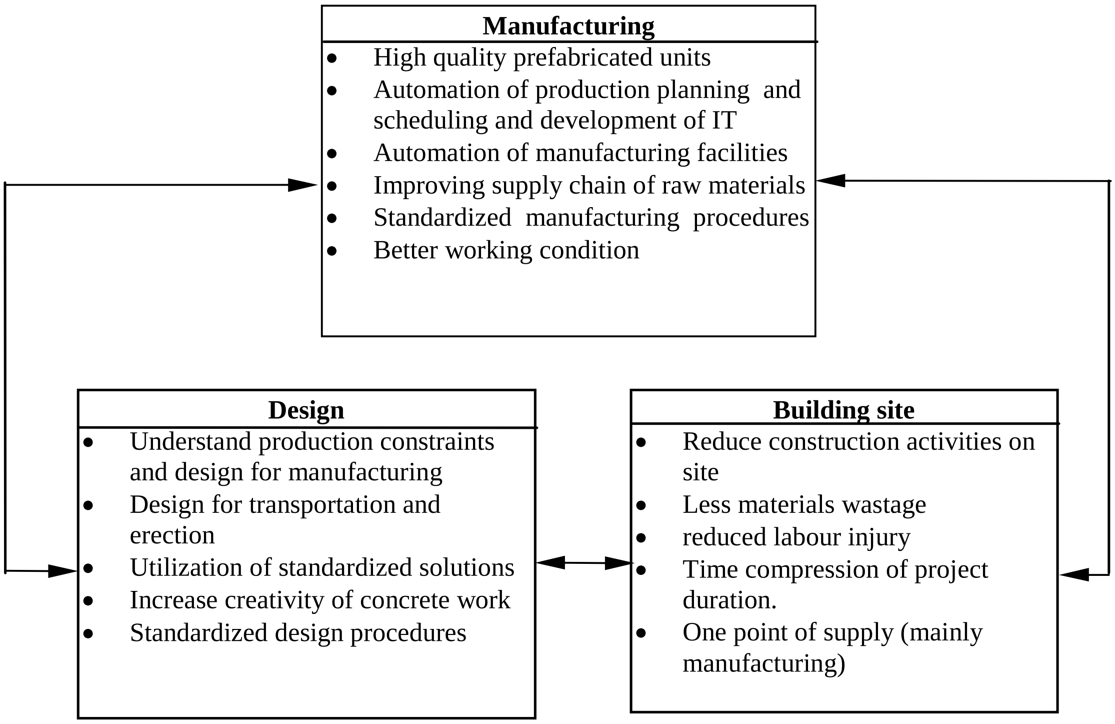

Figure 2: Potential advantages of the proposed integrated methodology

Figure 2 sets out potential advantages to be gained from the proposed development of an integrated methodology for the pre-cast business process, which has been identified from the survey.

The objective of this research is to develop an integrated intelligent computer-based design and production system for the pre-cast industry. The system should facilitate; the integration of design and manufacturing operations; automation of production schedules directly from design data and factory attributes and generation of erection schedules from site information, factory attributes and design data. It is hypothesised that the introduction of such a system would reduce the total cost of pre-casting by 10% and encourage clients to choose the pre-cast solution.

The following sections of the paper discuss the development of the theory of the model and designing the specification and the concept of the proposed model.

THE THEORY OF THE MODEL

The model developed in this paper is theoretically based on the CIM (Computer Integrated Manufacturing), and CIC (Computer Integrated Construction) models (Rembold, 1993). It consists of both the use of information technology in different phases and tasks of the manufacturing process (including design) and the integration of these phases and tasks through the use of digitally stored data and data transfer. Among the elements needed to create a computer integrated environment are (Bjork, 1992):

- The extensive use of data bases for storing design and project management data
- Intelligent user interface
- An infrastructure of data transfer networks
- Data structuring and transfer standards

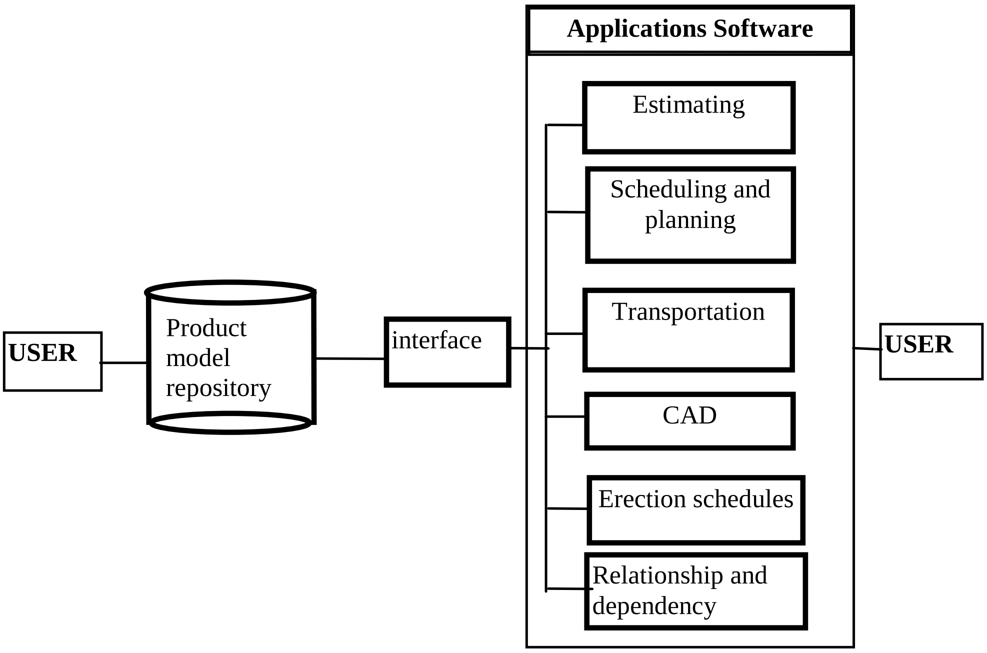

Figure 3: Structure of the proposed model

- Data and knowledge bases with general construction/manufacturing information.

The modelling approach adopted in this research is the conceptual modelling technique, which has been particularly popular in product model research. The approach focuses on modelling the structure of the information describing the products, processes, resources and other elements of the pre-casting process. A conceptual model specifies the categories of information used in a specific domain or database. In a conceptual model only the information itself is modelled, not the format in which the information is stored or presented.

A significant volume of construction-related product modelling research has been developed and reported by a tremendous amount of literature and amongst the models being developed are: RATAS (computer-aided design of building), COMBINE (energy-conscious building design), CIMSTEEL (construction steel work), ATLAS (large scale engineering), Process Base (process plants) and CAESAR Offshore (offshore project). The intention of this research is utilise the wealth of theory developed in such projects.

The basic concept used in almost all data models is the object or entity. An object is a set of closely interrelated data about “something” in the modelling domain, see Bjork (1992). “Something” can be a physical object, but it could be an equation system, or any kind of abstract object. Similar concepts to objects are frames in knowledge-base systems, abstract data types in programmes and the “objects” of object oriented programming. The overall concept of the research is to standardise the way in which engineering information, relating to a type of object (pre-cast units, moulds, etc.) is held to facilitate the transfer of such information between process models (applications software). The following section explains and discusses the structure and specifications of the proposed model.

THE STRUCTURE AND SPECIFICATION OF THE MODEL

The model is composed of a central “product model repository” where physical objects are modelled and stored. Such objects are pre-cast units and their attributes

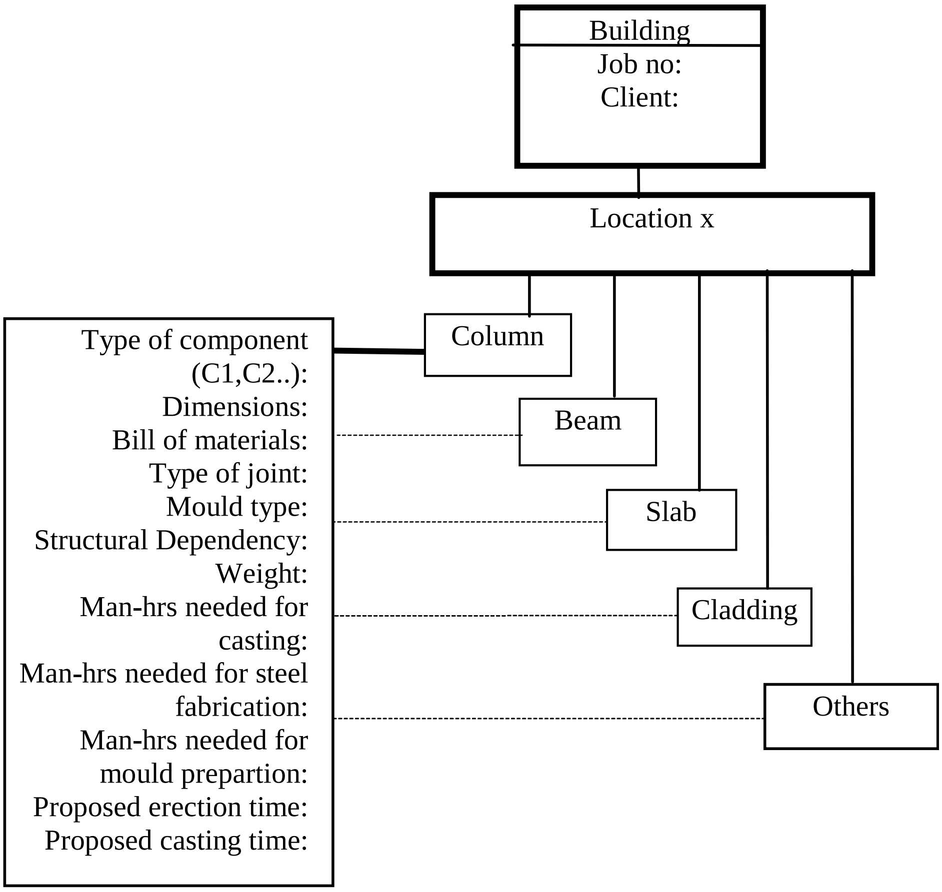

Figure 4. Structure for modelling information for a given job

and factory attributes. The objects are designed to interact with application software for the creation of application objects specifically tailored to a particular job, processing of information to produce plans and schedules. Figure 3 shows the structure of the model in terms of product model repository and applications software.

The data structure of the "product model repository" is designed to facilitate the transfer of information to different applications in a standardised way. Figures 4 and 5 show the structure for modelling information for the main objects in the model, namely building and factory respectively. As can be seen in Figure 4, the attributes for each sub-object are presented in terms of: type of component, dimensions, bill of quantities, type of joint, mould type, structural dependency, weight, man-hr. needed for steel fabrication, man-hr. needed for mould preparation, proposed erection time and proposed casting time. Some of the information is provided directly by users and some is a product of information processing by applications software. For example, dimensions and type of joint will be developed through CAD while Bill of Materials and Man-hr. needed for mould preparation and steel fabrication can be provided by the estimation software.

Figure 5 shows the structure for modelling production facilities. A factory is composed of moulds attributes, casting man-hr. available and transportation facilities. Production managers for each given period give the information describing the entities.

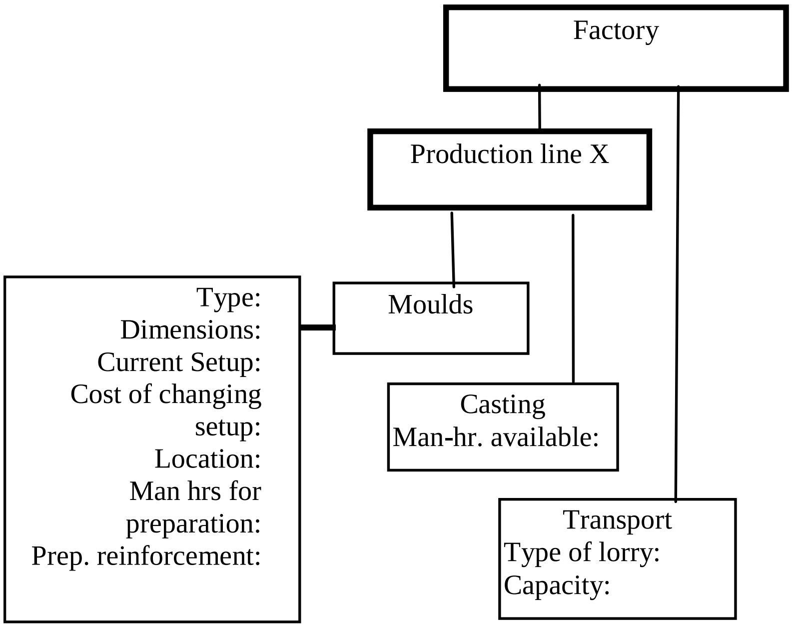

Figure 5: Structure for modelling factory attributes

The processes of the model

The processes of the model are the operations which use the objects discussed above, process their information and produce: relationship and dependency between units, erection schedule, and finally production planning and scheduling information. The processes are developed using integrated methodologies of KBS and heuristic rules, which are being developed from elicitation of knowledge from pre-cast production managers. The following introduces briefly the above processes.

Relationship and dependency of units

From previous literature (Kähkonen, 1993), it was concluded that factors affecting the sequence of project locations are contracts, site condition and working practice. The planner's decisions on the sequencing of individual pre-cast units are affected by structural factors, but safety, production technology and site conditions can also be important. Additionally, when defining the overall erection programme, the decisions are affected by resources, work area and safety. Typical factors of dependency are presented in Table 1.

Table 1: Typical factors which have an influence on dependency

Decision	Affecting Factors
1 Sequence of project locations	Contractual, site conditions
2 Sequence of pre-cast units	Structural, safety, erection technology and site condition
3 Overall erection programme	Erection equipment and resources, work area and safety

It is proposed in this research that structural relationship and dependency between pre-cast units in a given building location be established in the first instance. For example, columns to floor *i-1* precede beams to floor *i*. The information is presented in a hierarchical form or a network or dependency bar chart. The structural dependency will be then revised with respect to the availability of erection resources, which in turn reflect site condition and erection technology. The output of this process is the erection schedule, see Figure 6.

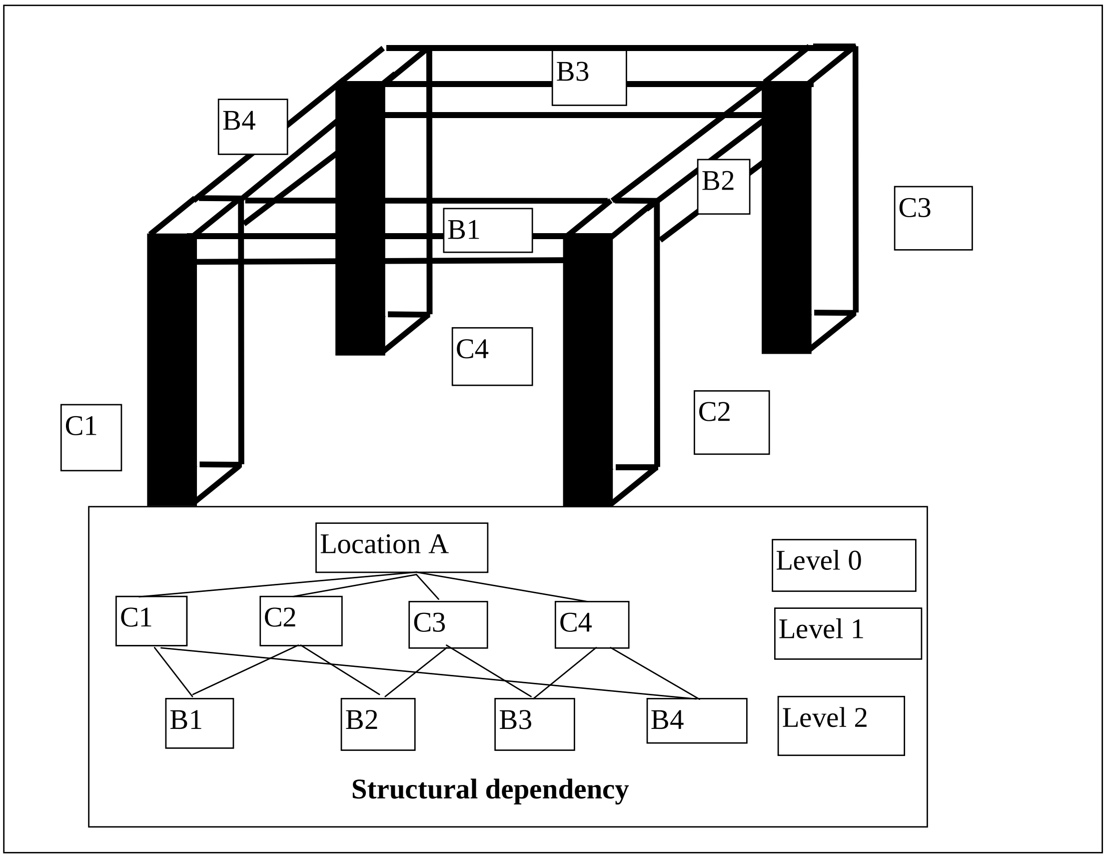

Figure 6: Example of the sequencing process

Erection schedules

These schedules are generated to reflect realistically the erection of pre-cast units on site. Once the dependency sequencing process is accomplished the output schedule will be refined and altered with respect to the following factors:

1. Erection equipment on site
2. Erection gang on site
3. Site conditions and working space that should be reflected in points 1 and 2 above.

In order for a pre-cast unit to be erected on site, resources are needed to accomplish this within a specified time. Planners should decide on this based on their experience. The total amount of resources available on site will be kept in a central pool and units will be competing for such resources. If resources are insufficient to accomplish the dependency network generated in the above section, certain units might be delayed until resources become available.

Production planning and scheduling

Once the erection schedule has been developed, the next process is to produce the pre-cast units. Each factory might supply several construction sites and the planning process in the system is accomplished as follows:

1. The erection schedule of pre-cast units, for a given building, is transformed into ALAPCS (As Late As Possible Casting Schedule) assuming unlimited capacity is available. This is achieved by calculating the minimum lead-time needed for

casting, curing and transporting of pre-cast units. The latest production time will be (erection time for unit (i)- (casting, curing and transporting of unit (i)).

2. The ALAPCS schedule is incorporated in a mould schedule. The system searches for available moulds in the shop and compares them with the required moulds for units. If the available moulds are sufficient, then the ALAPCS schedule will be converted to a mould schedule after subtracting the mould set-up time and other requirements that are needed before casting. Otherwise, the ALAPCS will be altered using the backward scheduling technique (Dawood, 1996). In this case, certain units might be produced earlier than they should and therefore provision for stock holding should be considered. The main criterion used in the evaluation of different moulds allocation is to minimise mould changeovers.
3. Once a mould schedule is produced, the system automatically produces steel fabrication schedules for the moulds.

CONCLUSIONS

The pre-cast industry is set to play a major role in improving construction productivity and quality and reducing cost. The pre-cast industry, however, is lagging behind other manufacturing based industries in terms of its utilisation of IT in managerial and technical decisions. This has severely affected the competitiveness of the industry compared with traditional construction works.

The objective of this paper was to introduce and discuss the specifications of an integrated intelligent computer-based information system for the prefabrication industry. The theory of the system has developed using the "conceptual modelling technique". Product and process modelling procedures have been developed and discussed.

The main focus of the paper was the development of the structure and specification of the models. Three main processes of the model have been developed and discussed, these were:

1. Relationship and dependency of pre-cast units,
2. Erection schedules and
3. Production planning and scheduling.

Future development of the research will include the development of the computerisation aspects and validation of the model. Re-engineering business process of pre-casting will be tackled parallel to the software development.

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