An Integrated Intelligent Planning Approach for Standardised Prefabricated Components

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ABSTRACT

Design, manufacturing and erection activities of prefabricated units are highly complex, fragmented, time consuming and demand expert personnel. A recent study by the author revealed that the prefabrication industry is highly fragmented, manual intensive and behind other manufacturing based products in terms of information technology and automation. This is causing an extra financial burden on the industry and deprives the construction industry from sustainable growth. In this context, the objective of this research is to develop an integrated intelligent planning approach that automates the process of data exchange between design, manufacturing planning and erection scheduling, re-engineer business process of prefabrication and generate production plans. The paper focuses on the specifications of the main activities in the proposed approach. Such activities are: generating 3D model of a building; relationship and dependency between prefabricated units; erection schedules and production planning and scheduling. The theory of the proposed approach has been introduced and discussed.

1. INTRODUCTION

Prefabrication of building components and off site manufacturing offer the greatest potential for radical improvement of productivity and quality in building.
A factory production environment usually provides higher technological efficiency, better working conditions and more rigorously enforced quality control [1]. 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 bare minimum and off-site manufacturing should be increased [2]. It has also been stated that development of improved off-site fabrication through the introduction of coherent planning systems and CAD/CAM is likely to reduce cost and shorten construction times. The prime objective of this research is to develop an integrated intelligent planning approach for prefabricated construction that should re-engineer business process of prefabrication, automate production planning of precast elements in a

factory and provide integration with design and construction sites. The system should be able to generate production plans, simulate manufacturing processing and sequences to make a part. It is hypothesised that the system should tremendously reduce the manual efforts currently practised in the industry, increase planning efficiency and reduce production cost through optimising the efficiency and utilisation of manufacturing facilities. The system is designed to integrate and automate managerial and operational decisions for generating rapid and accurate information. Lead times for products are expected to decrease by 10%-20% over current practices and this should provide competitive edge for precast construction over other means of construction materials.

In a manufacturing environment, the applications of computers have had a substantial impact on almost all activities of a factory. Often, the introduction of the computer changed the organisational structure of a department and made necessary the adoption of completely new management structure. Since the computer is capable of doing repetitive work very efficiently, the task of many management functions has also changed drastically. The model developed in this paper is theoretically based on the CIM (Computer Integrated Manufacturing) approach [3]. The CIM combines the activities of CAD (Computer Aided Drafting), CAP (Computer Aided Planning) and CAM (Computer Aided Manufacturing). The CAP activities of the proposed system is fully explained and discussed in this paper and can be considered as the focal point.

The paper introduces the specifications of the proposed approach in terms of decisions and processes which is regarded as phase 1 of the research project. Phase 2 of the project is currently under development and concentrates on the software and organisational aspects of the system.

The following sections introduce the benefits and specifications of the proposed system.

2. THE BENEFITS AND APPLICATIONS OF THE PROPOSED SYSTEM

In a survey of current production planning practices in the UK, the author [4] has concluded that practices are fairly basic, manually driven, time consuming and inaccurate. It was also concluded that communications between construction sites and factories are somewhat primitive and some form of automation is needed. It is hypothesised that an automatic integration and generation of off-site manufacturing plans can bring significant savings in human efforts and enhance the quality of production plans. The system is designed to be utilised in multi-storey offices, houses and car park type of buildings and where standardised precast components are used. It has been concluded, during this research work, that rationalisation and standardisation of building components would be best achieved by forming groups of units by type, e.g. Beams, Columns, stairs and walls. Each type of component would be sized in increments of section and length, for example columns might start at 300 x 300 mm with a range of sizes such as 300 x 3500 mm, 300 x 400 mm, 400 x 450 mm etc. Beams and walls can be treated in the same way. The commercial benefit would be that suppliers should have greater certainty of the products which will be specified and bought. This means that manufacturers could invest in equipment and perhaps stock the more popular shapes and sizes.

3. SPECIFICATIONS OF THE PROPOSED INTELLIGENT SYSTEM

The purpose of the intelligent system presented here is to generate from the architectural and structural drawings, detailed erection and production schedules and to provide integration between parties in construction, design and manufacturing. Figure 1 shows the main processes of the system and the following states the attributes of such processes:

I. Generating a 3D detailed model. Once detailed information about design is finalised, the system should produce elevations and a 3D model of the building. This should be achieved in order to establish structural dependency of the precast units. The structural details of connections and joints will be generated using standardised procedures embedded in the system. CAD comprises computer supported design, drafting and engineering calculation.

II. Relationship and dependency between building locations and building units. It is proposed that a building will be split into locations and each location will be composed of precast units that have some form of structural dependency. A methodology has been developed to generate dependency of precast units and the output of this process is in a form of locations and units sequencing. More discussion regarding this process is given in the coming sections of this paper.

III. Development of erection schedules. Once the sequencing process has been achieved, the system converts this into erection schedules using resources available on site for erection, units attributes, erection time for each unit, site layout and client preferences. Users can interact for modifications, more discussion is given to following sections of this paper.

IV. Production planning and scheduling. Information generated in the above processes will be used to produce a production schedule. Factory attributes, construction site schedule and knowledge production rules will be used to achieve this process. More explanation of this is given in the following sections of this paper.

4. RELATIONSHIP AND DEPENDENCY BETWEEN BUILDING LOCATIONS AND PRECAST UNITS

From previous literature [5], it was concluded that factors affecting the sequence of project locations are contracts, site condition and working practice. The planner's decisions on the sequence of individual precast units are affected by structural factors, but safety, production technology and site conditions can also be important. Additionally, when defining the overall-lap of erection, the decisions are affected by resources, work area and safety. Typical factors of dependency are presented in Table 1.

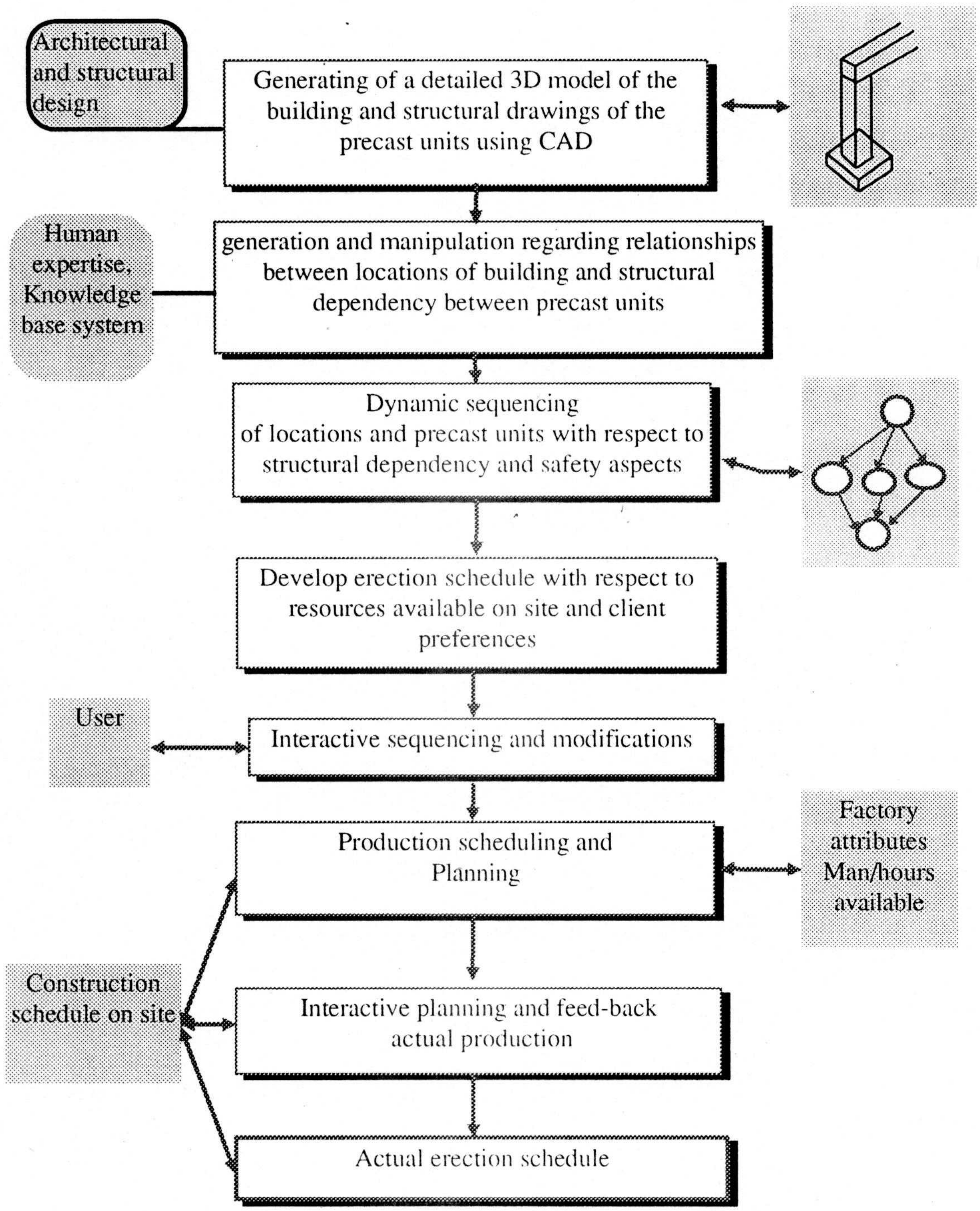

Figure 1: The flow chart of the system

Decision	Affecting Factors
1 Sequence of project locations	Contractual, site conditions
2 Sequence of precast units	Structural, safety, erection technology and site condition
3 Overlap of erection	Erection equipment and resources, work area and safety

Table 1: Typical factors which have an influence on dependency

It is proposed in this research that structural relationship and dependency between precast units in a given building location is established in the first instance. For example, columns to floor i precede beams to floor i. The information is presented in a hierarchical form or a network or dependency bar chart. The structural dependency will then be 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. Planners should be able to interact with the process and make modifications to suite contractual arrangements if needed. The procedure for automating the dependency (sequencing) process is as follows:

I. The project will be split into locations. A location dependency schedule will be produced which is based on contractual and site condition. For example, a multi-storey building might be split into floor locations. This process is achieved manually and a code will be attached to each location. Each location will be known as a high level object.

II. Each location will then be decomposed into precast units which is known as sub-objects. The relationship between the units is generated automatically using a knowledge-base and constraints available in the model. This is achieved as follows:

   a) For each location, the structural engineer should identify the structural relationships between precast units and store them in the code system of each unit. The relationships will be presented in a form of a dependency hierarchical form as shown in figure 2. The figure shows a location in a building which is composed of four precast columns and four precast beams. The structural dependency states that the four columns can be erected at the same time and beam code B1 is dependent on columns code C1 and C2, beam code B2 is dependent on columns code C2 and C3 and so on.

   b) Once the 3D model of the whole building is developed and locations are identified, the structural dependency of precast units should be established and embedded in the unit's universal coding system. A knowledge-base is developed to generate dependency charts from the codes of individual units. The output information of this process is a logic dependency network or bar chart.

   The following section introduces the process of producing erection schedules.

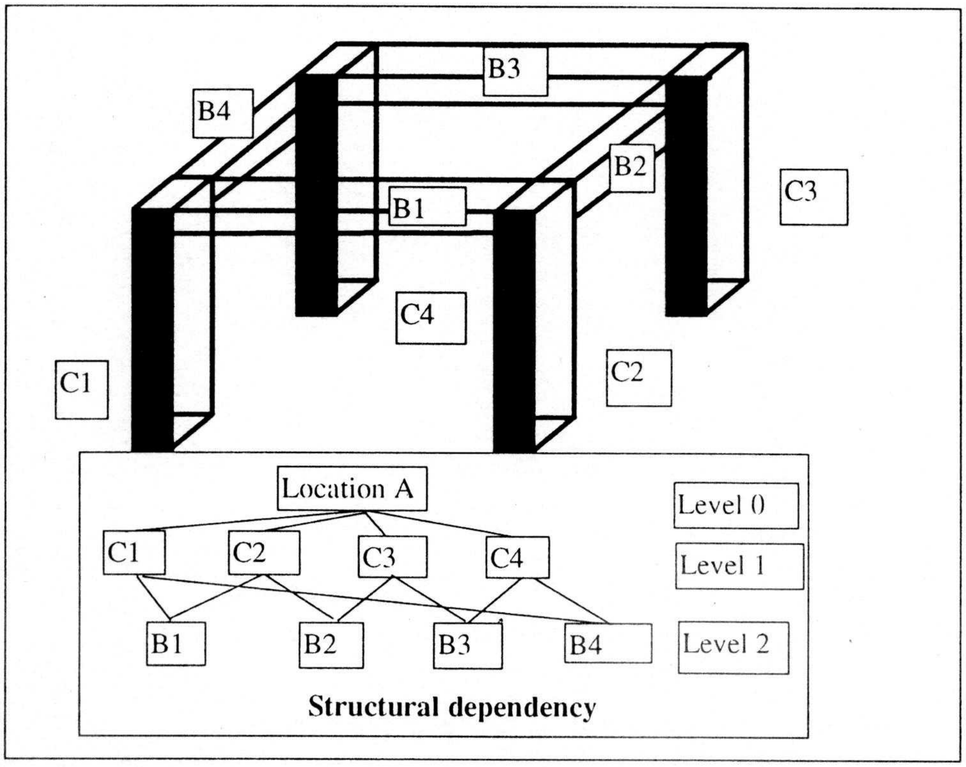

Figure 2: The sequencing process

5. ERECTION SCHEDULES

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

I. Erection equipment on site
II. Erection gang on site
III. Site conditions and working space which should be reflected in points I and II above.

In order for a precast unit to be erected on site, resources are needed to accomplish this within specified time. 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 not enough to accomplish the dependency network generated in the above section, certain units might be delayed until resources become available. In this case, priority rules are to be used:

I. units with high erection time have high priority compared to other units.
II. big units have priority over small units.

In the example given in Figure 2, the four columns can be erected at the same time. However, if one Crane is available on site, the four columns cannot be erected at the same time and revised schedule will be produced which should indicate that the columns will be erected sequentially and not concurrently. Once an erection schedule is developed, the next stage in the process is to produce factory production plans.

6. PRODUCTION PLANNING AND SCHEDULING

Once the erection schedule is developed, the next process is to produce the precast units. It is normal practice that units are produced in a factory (which might be far away from the construction site) and transported to the construction site. A building might be produced from several factories and each might be specialised in a particular range of units. The erection schedule should, therefore, be filtered for each factory with regard to the capacity available. For example, columns and beams should be produced in factory (A) while the slabs should be produced in factory (B). Each factory might supply several construction sites and the planning process in the system is accomplished as follows:

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

II. The ALAPCS schedule is then incorporated in a mould schedule. The system searches for available moulds in the shop and compares them with the required moulds for units. If available moulds are sufficient, then the ALAPCS schedule will be converted to the 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 [6,7]. 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. It should be mentioned that mould schedule is considered to be an important operation in a precasting shop and cost of production can be increased rapidly if moulds are not utilised efficiently and effectively. Set-up changes should be minimised in order to reduce cost. In a study of the effect of mould's changeovers and repetition of casting in a precasting company, it was concluded that the cost of a precast unit produced in a special mould which is used to produce 2 or 3 casts is five times greater than a precast unit produced from a mould which can produce 30 casts of the same units, see Figure 3.

III. Once a mould schedule is produced, the system automatically produces steel fabrication schedules for the moulds.

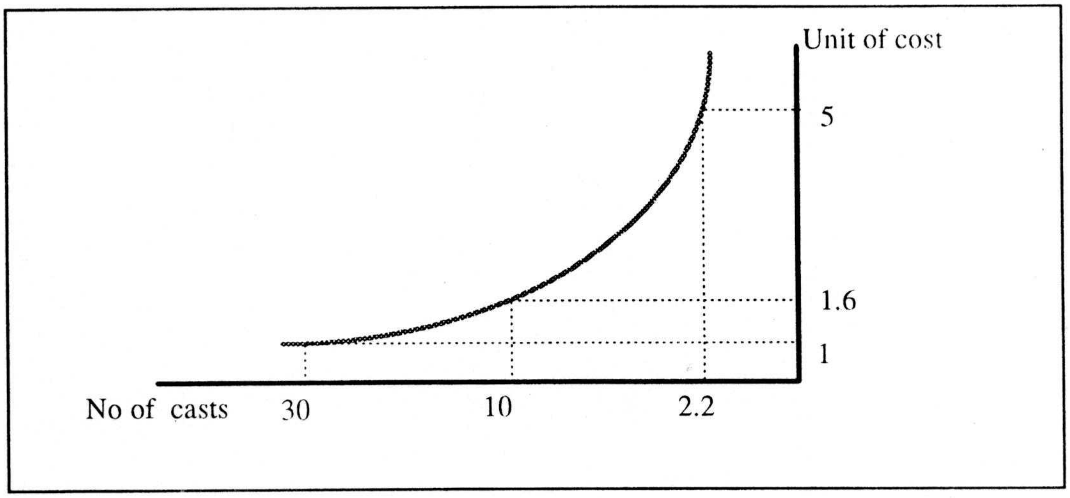

Figure 3. Cost/cast graph

Scheduling knowledge rules are developed and encapsulated into the scheduling process. The rules are developed to mimic the decisions needed to accomplish the scheduling process. Amongst these decisions are:

- queuing of coming orders with respect to certain priority loading rules [5].
- grouping of similar units from one or more buildings.
- allocation of moulds to precast units.
- update and revision of schedules with respect to information feedback from the site.

The knowledge scheduling rules are developed to satisfy the following criteria:

- efficient utilisation of resources by minimising changeovers of moulds
- satisfy erection programmes
- minimise disturbances in the shop floor

The planning and scheduling process is meant to be interactive and schedules should be able to modify and alter as work progresses.

7. CONCLUSIONS

The objective of this paper was to introduce and discuss an integrated intelligent planning approach to prefabrication of buildings. The proposed approach should automate the process of data exchange between design, manufacturing planning and erection scheduling. The paper has focused on the specifications of the main activities in the proposed approach. Such activities are: generating 3D model of a building; relationship and dependency between prefabricated units; erection schedules and production planning and scheduling. The theory of the proposed approach was based on the CIM approach which is proven to be fairly effective in the manufacturing environment. It was concluded that an automatic integration and generation of off-site manufacturing can bring significant savings in human efforts and enhance quality of production plans. The system was designed to be utilised in multi-storey offices, houses and car park type of buildings and where standardised precast components are used. The next stage of the research work is focused on the software development.

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