A STUDY OF THE ROBOTIC REQUIREMENTS OF A MAJOR CONTRACTOR

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ABSTRACT

The increasing concern within the construction industry over the future decline in the labour market has prompted a need to investigate alternative construction methods, particularly automated or robotized ones. A method for researching these issues in relation to the work of a major contractor and for identifying the technical and economic feasibility of various possible developments is presented in this paper. Sources of information are identified and their use discussed. A detailed approach to collecting data for a specific example, namely reinforced concrete column construction, is included and initial findings reported.

INTRODUCTION

Britain, like many other developed nations, is presently facing a demographic time bomb in which the number of 16 to 19 year olds entering the labour market will have reduced by 25 percent in the period between 1987 and 1993 (1). This problem, combined with the continuing decline in people entering the construction industry, the associated deskilling of the labour force and the new challenges facing the industry with growing European unity and Japanese competition, has resulted in the realization that methods must be developed both to counter these effects and to take advantage of the resultant changes (2). One possible approach to solving this problem is to consider the application of automation and robotics to site construction processes. For the introduction of alternative construction methods to be successful it is important that those areas of work that are 'good candidates for automation' (3) and which would fulfil a real need (4) are chosen for development.

Tarmac Construction Major Projects Division, which presently has a turnover of £400m per annum and undertakes major building and civil engineering contracts valued between £20m and £100m, has decided, in conjunction with Nottingham University, to investigate the possibilities of automating or robotizing aspects of its construction work. This research therefore examines the nature of the company's work, the methods used in construction and the productivity achieved, with a view to enhancing competitiveness and overcoming the envisaged labour shortage.

The purpose of this paper is to introduce a method for deciding which aspects of work might be selected for automation, robotization or standardization, in a way which maximizes the benefit to the company. The background to the work and the adopted methodology are discussed. Details of a data collection exercise for one aspect of building work are included with an example and a brief analysis of the results obtained. The example chosen is that of reinforced concrete columns and the results are used in a discussion of the issues facing the research in addressing the company's interests.

BACKGROUND

A number of alternative methods for assessing the suitability of construction work for automation or robotization have been proposed (e.g.(3),(5) and (6)). These methods have isolated a number of global tasks or trades as areas that are worthy of further investigation and being rated within their particular classification system. The main areas have been identified by brain storming (3) or systematic examination for possible adaptation to robotization (7). Several points emerge from the methods which would limit their application to this research:

- The proposed task identification and weighting systems have been developed with the assumption that the application of high level robotization is the solution, with the resultant risk that low technology or labour enhancing tools may be ignored (2).
- The headings are of such breadth that, within a category, individual tasks or elements of work which could benefit from some form of robotization, automation or even standardization could be overlooked because of the other tasks within that category being clearly unsuited to further development.
- The selection of the construction processes does not necessarily reflect those areas that require review within a particular organization.
- The classification systems assume that robots would perform a pivotal role in the automation of existing construction processes (8). (This presumes that complex tasks could not be redesigned, either to aid automation or to reduce the difficulties and hazards of the task.)

One aim of this research is therefore the development of a task identification system which would enable the work undertaken by the company to be examined in more discrete categories than previously. This would facilitate the assessment of:

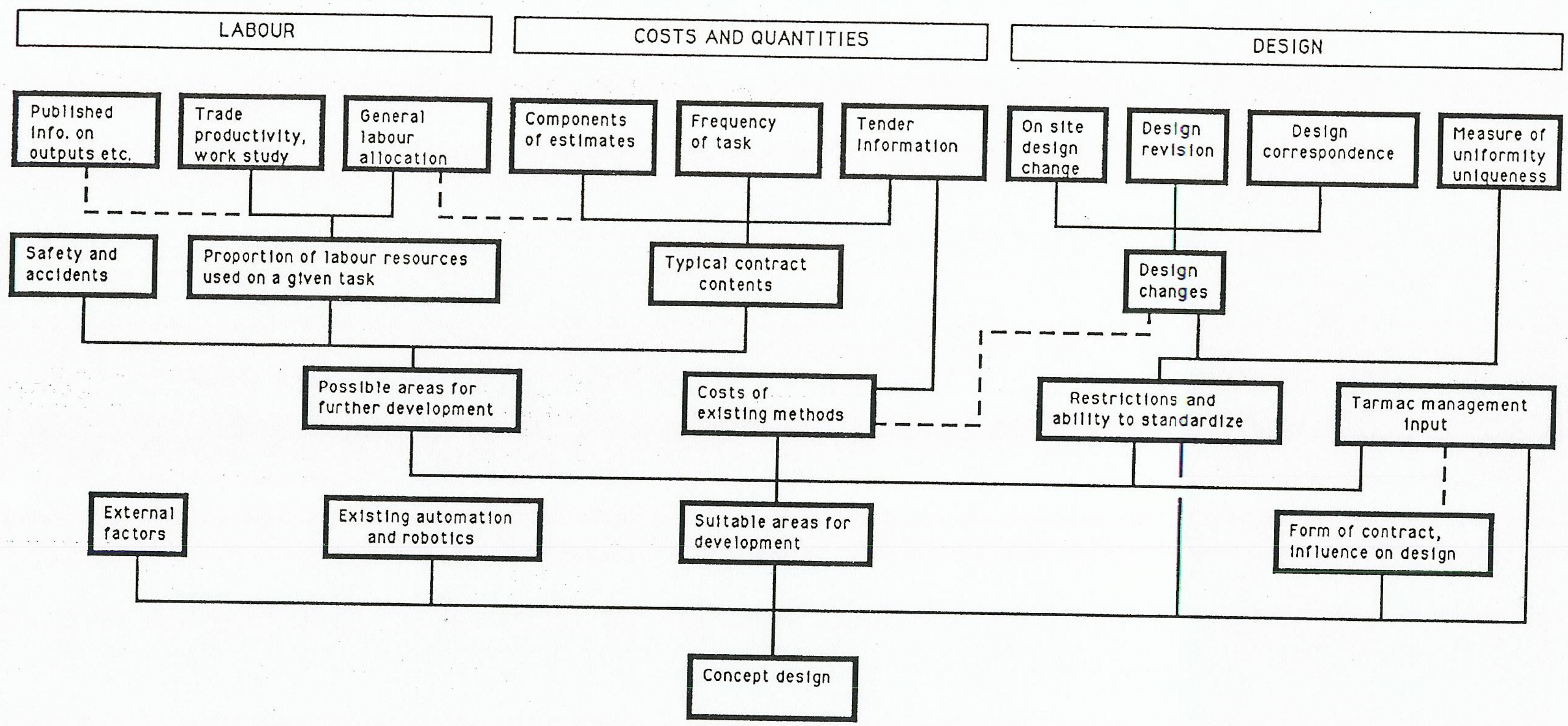
- which tasks or building elements could be simplified or standardized,
- which tasks could be automated,
- which tasks were of sufficient significance in terms of volume, cost or disruption to warrant developing alternative, possibly automated, construction methods.

METHODOLOGY

A method of developing a task identification system for this research has been proposed and data has been collected to aid its development. The frequency and complexity of a task has been measured so that a revised working method could be developed for either an element or an entire component of work. The revised methods might require high level robotization, which would necessitate the application of an 'Ergonomic Analysis Framework' (9) in order both to evaluate the attributes that the resultant robot would require and to quantify the technical problems associated with automating that aspect of work. Alternatively the revised method might involve the reconfiguration of an existing construction process, the development of a standard component or the production of a guide recommending design parameters.

Figure 1 illustrates the adopted approach to data collection and analysis. The approach is designed to enable a full review of relevant criteria to be carried out and can be considered in three main categories: Labour, Costs and Quantities and Design.

- The labour category is used principally to examine the number of hours spent on any given task or element of work and the additional labour resources that are used to assist the trade operatives. These figures are determined by referring to labour allocation sheets, published and internal information on outputs and work study.
- The costs and quantities section of the study is used to determine the composition of works both undertaken and tendered for, so as to enable the relative importance of a task to be assessed. These two major categories are then used to provide a measure of the probable costs and quantities associated with a given aspect of work.



Data collection flow chart for Automation and Robotics Research

Figure 1

- The design category is used to measure the technical content of the work and any restrictions that may prevent automation, standardization or robotization, whether they are due, for example,to complex or unique details or to the high costs of altering the system should late design changes occur (10).

The following section of the paper is concerned with outlining general aspects of data collection and the particular method for collecting information about one component of a building's structure. This enables a preliminary assessment of the feasibility of automating or standardizing either the entire component or a discrete element of it to be undertaken.

COMPONENT DATA COLLECTION

Before evaluating the feasibility of robotizing or automating the construction of a building component it is first necessary to have evaluated 'all the steps that must be performed to complete the process' (9) using current construction techniques. The method of data collection should be designed so that it provides the information on the performance parameters that an automated system would require, whilst ensuring that the information gathered is of sufficient breadth so as not to limit the type of technology under consideration (2).

The method of data collection for any component should therefore provide information on :

- the variety of shapes for that component,
- the frequency of their occurrence,
- the number and type of elements that form the component,
- the frequency and form of any special features,
- the locality and the restrictions that this may place on altering the methods.

This information is collected from a wide range of projects and is examined to assess whether any aspect of the work is technically suitable for redesign or automation. The decision on whether to proceed is dependent on whether the costs and labour requirements for the task indicate sufficient need and economic justification.

To illustrate the data collection process, the method developed for part of a building's structure is considered. The structure was chosen because it is an important aspect of a contractor's work and can be a cause of significant delays to project progress. Following a period of site evaluation and familiarization, some standard forms for various elements of the building structure were developed, to assist in collecting the broad range of information required. Figure 2 shows a partly completed data collection form for analysing reinforced concrete column construction. The information to complete this form is obtained from the associated reinforcing and general arrangement drawings and by on site observation. It is used to collect the information required as explained below:

- Sections A-E provide global information on the size and shape of the columns, from which it is possible to determine whether sufficient repetition of size and type occurs to make the development of standardized formwork or precast system viable. It also provides information on the degree of adjustment that a modular system would require.
- Sections B and C provide a concise method of recording special information. For example a 'V' shaped column or a splayed head column could both be simply represented.
- Section E records the free height of the columns, which is measured over any downstands or upstands and provides a guide to the degree of flexibility that any modular or manipulatory system would require.
- Section F records the ease of access to the column on a five point scale (0-4), as illustrated in Table 1. This table has been developed with a view to full automation being used for column construction and is concerned with the free volume of space around a column in which the assembly and manipulation would have to take place.

Columns Form

Site :	
Designers Phone No. Contact	
Date	
Precast or Insitu	

SFB Rev D
27 Feb 90

A	No. of columns																	
B	Plan shape (draw)																	
C	Elevation (draw)																	
D	Dimensions																	
E	Free height																	
F	Ease of access (see notes)																	
G	Quality of finish reqd.																	
H	Special features																	
I	Ease of redesign (*see notes*)	A																
		B																
		C																
		D																
J	Reinforcement no. type & size																	
K	Links	centres																
		No. per level																
L	Grid Reference																	
M	Level																	
N	Load KN	Axial																
		Bending																

Ease of Redesign	0	1	2	3	4
A Position (for columns integral with full height walls, see wall form).	OR WALL	OR UPSTAND	DOWNSTAND	ON EDGE	
B Adjoining details (full height)	IN CORNER	OBSCURED	OBSCURED	ON EDGE	CENTRE OF SLAB
C Main steel	COMPLEX OR SPLAYED HEAD	COMBINATION	BOBBED	CRANKED	STRAIGHT
D Links arrangement and shape (BS. 4466, 1989)	COMPLEX LINK ARRANGEMENT	TWO SHAPE 61 ONE SHAPE 52 OR ONESHAPE 61 TWO SHAPE 82	ONE SHAPE 61 TWO SHAPE 52 OR ONE SHAPE61 ONE SHAPE 82	ONE SHAPE 61 ONE SHAPE 52	ONE SHAPE 61 OR SHAPE 87

Figure 2

The horizontal floor distance is measured from the nearest major floor opening or vertical element (excluding adjoining columns or upstands of less than 150mm).

		Horizontal Clear Distance (m)				
		0-2	2-4	4-6	6-8	8+
Height	0-2	2	4	4	4	4
of	2-4	1	3	4	4	4
Column	4-6	0	1	2	3	3
(m)	6-8	0	0	1	2	2

Table 1 - Ease of Access

- Section G records the quality of finish required and conforms to a recommended specification method.
- Section H records the inclusion of special features within the columns, such as conduits, slots for masonry fixings and corner guards for protection from vehicle impact. This information assists in determining what restrictions to impose on the design and operation of a standardized or automated system.
- Section I classifies the elements of the column that affect the ease of redesign, and has been divided into four main parts, illustrated at the bottom of Figure 2:

  Parts A and B are concerned with the shape and position of the column respectively. For example, a column that is built integrally with an upstand wall (A0) would greatly complicate the provision of either a standardized formwork system or an automated assembly process, whilst a column that is positioned on the edge of the structure (A3) would require a different method of formwork assembly, and robotic and tolerance control than a simply positioned column (A4, B4). If a column were positioned so that it immediately adjoined an existing wall (B1), this would prevent the use of standardized formwork and necessitate special programming of an assembly robot in order to manipulate the materials in the restricted space and also to adjust its operations to suit the as-built positions of the adjoining components.

  Part C classifies the main column reinforcement in order to help determine whether the reinforcement is suitable for automated prefabrication using a cage fabrication system.

  Part D classifies the arrangement of reinforcing links in accordance with BS 4466 (11) and categorizes them in accordance with the difficulty that their shape might cause in automated fabrication (12).
- Sections J and K provide supporting information to the previous section and indicate the number, size and weight of materials to be handled.
- Sections L to N are used to record the loadings imposed on the columns.

Whilst the data contained within each of these sections may be considered in isolation, it is generally beneficial to cross reference. For example, it may be found that, for given loading conditions, there are variations in column sizes. Overcoming this could make an automated fabrication system economically viable.

DATA ANALYSIS

The data collection form (Figure 2) has been used to record information on 1120 columns from three separate projects, yielding some key results which are detailed below:

- **Seventy percent** of columns are designed with complex link arrangements (Section I, categories D1 and D2) which are uniformly light in both size and distribution.

- **Eighty percent** of columns are designed with heavy (T32 or greater) reinforcement, which is required to be bent in **ninety percent** of cases. Automating this would require technology capable of manipulating and orientating heavy components.
- **Sixty percent** of all columns are built on the edge of slabs or adjoining upstands and walls.
- **No apparent uniformity** in size or shape of columns exists.

DISCUSSION

The results obtained from this initial survey represent the current situation on many building projects where in situ concrete construction techniques are used in so far as design details rarely consider the use of automated construction techniques or even manual buildability. The information gathered could therefore be used to assist in rationalizing the range of building elements (10) and in preparing a set of preferred design parameters to maximize the usage of advantageous construction methods (13).

Each of the results listed above highlights areas where standardised, possibly automated, techniques could be deployed. These areas are:

- Standardisation of link reinforcement,
- Design using unbent heavy bars,
- Eliminating complications with connecting members,
- Standardisation of shapes of columns.

These points are similar to many which could be made about other areas of work and serve to illustrate a limitation from a contractor's point of view. This limitation is the separation of the design, manufacture and construction teams, which prevents the introduction of innovative construction methods and even the simplification of designs to aid conventional construction (14).

Despite this the study should also be able to identify aspects of a contractor's work where automation or robotization will yield real benefits to the company and give an acceptable return on its investment. The method of data collection has been specifically designed with this in mind. When the whole spectrum of data analysis is more advanced it will be possible to see benefits in the following areas:

- low level labour saving technology,
- partial or entire automation of tasks,
- high level robotization.

Labour saving technology could be directed towards getting tasks done faster or by fewer people or by different types of employee (e.g. women, less skilled workers or highly trained workers). At the lowest level, developments would simply involve making improvements to familiar manual tasks. In relation to reinforced concrete column construction, possible areas to consider on technical grounds would be the bending, fixing or transporting of reinforcement, the placing or vibrating of concrete, and the fixing or handling of formwork.

It should also be remembered that economic considerations of the uptake on developments are important, so proposals which could be implemented manually as well as through automation, or which could be used on a range of components, could increase the viability of the development.

CONCLUSION

This Paper has introduced an approach for assisting a major construction company to identify aspects of its work which could benefit from automation or robotization. It has referenced several articles of a more general nature in reaching its proposed methodology. The intensive data collection method required should be linked with information obtained from other sources, both to ensure that the resultant information is appropriately directed and so that any further development work reflects the company's future perceived needs.

More specifically the Paper describes a method of examining the composition of a component of work and of identifying the technical problems that would limit the introduction of an alternative construction method. The selection of tasks to be subjected to this form of examination should be based upon first having examined the associated labour, plant and materials requirements and secondly knowing the frequency with which the task is undertaken. The resultant information may then be used in one of three ways:

- The preparation of performance parameters for an automated system, which would then be further examined using an 'Ergonomic Analysis Framework'
- The design of modular or standardized components which are both economic and flexible enough to cope with a variety of technical and design restrictions.
- The development of a buildability knowledge base to aid in the simplification of the design and to reduce the difficulty of introducing either standard components or automated systems.

By implementing the methodology discussed it will be possible to determine which aspects of the company's operations could benefit from either automation or standardization and to develop the performance requirements of proposed systems.

ACKNOWLEDGEMENT

The authors would like to thank Tarmac Construction Major Projects Division for the financial and technical support provided for this project.

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