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TASK DECOMPOSITION IN SUPPORT OF AUTOMATION AND ROBOTICS IN CONSTRUCTION

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Abstract

In order to define the requirements for automation and robotic technologies as applied to the construction industry it is necessary to consider the task structures within which these technologies are to be applied. This in turn implies that any particular task or activity for which automation is to be applied must also be considered in relation to its system context.

The paper therefore considers the hierarchical decomposition of tasks down to the level of the discrete movements of the manipulator arm required while retaining the ability to view the system at higher levels in order to establish the flow of both procedural and process data associated with the task. From this basis it is possible to consider the system requirements at a variety of levels and to introduce simulations of both system level and discrete functions in order to establish the operational and information structures.

1. INTRODUCTION

The structure of an integrated robotic system for construction would be very similar to that found in other industrial applications. However, due to the nature of the in-situ environment and the wide range of activities and resources involved in the construction process it is apparent that there is a need for a more dynamic and adaptable system when compared with its industrial counterparts. The overall system can be divided into three hierarchical levels [1,2] as suggested by figure 1.

The top level constitutes the management and decision making resource. Here, data is gathered, critically analysed and acted upon at the system level. Run-time information as well as data on planning and resources are held by the intelligent database system and are accessible at both the top and lower levels.

The middle level represents the communication between the individual elements of the integrated system. This is analogous to those found in manufacturing but will need to be based on a medium suitable for the construction environment.

The lower level represents the on-site the automated and robotic hardware and encompasses fully-automated, semi-automated and teleoperated systems. Also at this level are the site systems which provide direct, on-line facilities to users at the site level together with a local data base and resource system.

In the study, the focus is primarily, but not exclusively, on the lower level of this hierarchy where the actual automated and robotic functions take place. This involves the decomposition into their elemental tasks of the processes involved in a particular activity following which they can be examined dynamically using computer based simulation tools.

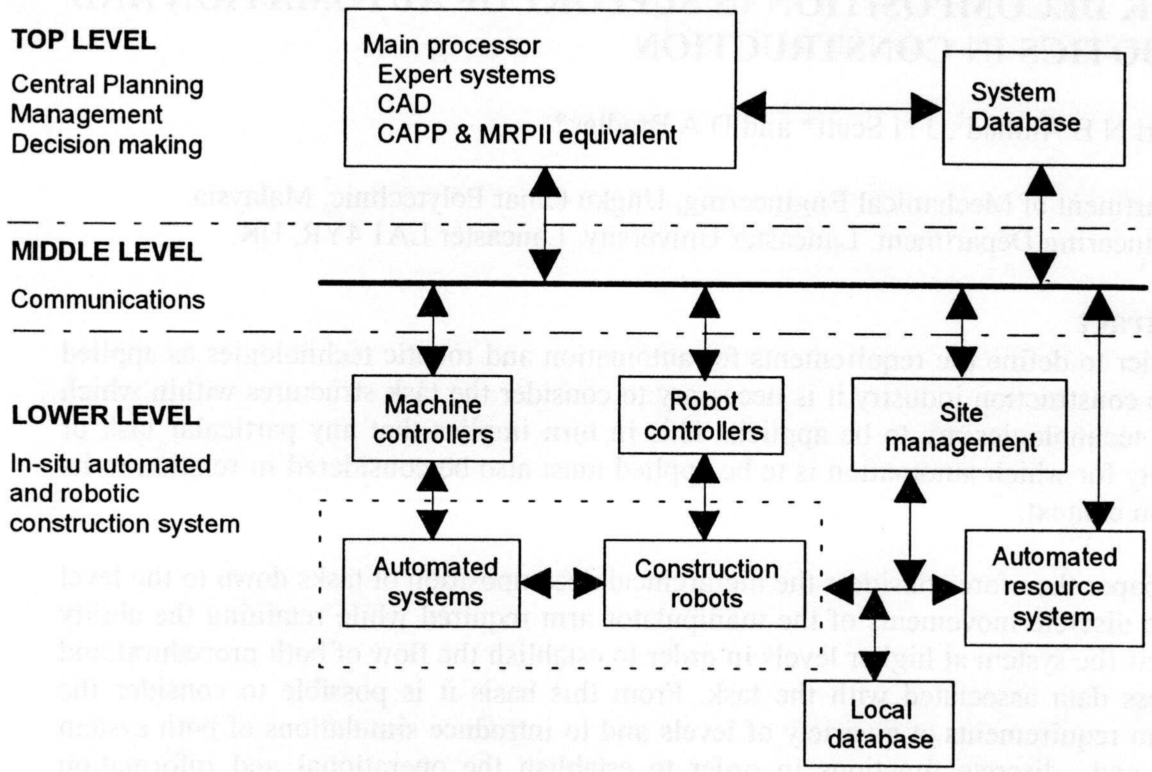

Figure 1. *A hierarchy for automation and robotics in construction*

2. PROCESS HIERARCHY AND DECOMPOSITION

The construction process is composed of a complex interaction of hierarchical activities within which it accomplishes its goal. For such processes to be automated, it is necessary to understand the interrelationships between the individual activities in order to identify at which level or cluster of levels the implementation of automated and robotic functions could be achieved.

In principle, the operation of any automated or robotic device consists of a series of sequential elemental movements to represent the intended process. A pick-and-place manipulator and an automatic conveyor are classic examples of devices that accomplish their task through a series of repetitive movements and represent a classical transport process.

Tucker et al [3] have proposed that construction activities can be represented by an *area - activity - task* hierarchy. Here, the *area* is taken to be the type of construction process that is taking place when the *activity* is

AREA	ACTIVITY	TASK
Foundation	Earthworks	Excavate earth
		Fill soil
		Level ground

Table 1. *Area-activity-task hierarchy*

then the effort performed as a part or stage of the area. Activities can then be broken down into a number of *tasks* which represent the lowest level of the structure. An example of this structure is given in table 1.

Everett et al. [4] devised a more elaborate structure referred to as a hierarchical taxonomy in which the construction process can be decomposed into seven descending levels as in table 2.

LEVEL	DESCRIPTION	EXAMPLES
Project	Defines type of construction and defines its general attributes such as time, budget and resource allocation.	Building, drainage, tunnel and bridge works
Division	The breakdown of the project into its principal divisions of work.	Concreting, foundations, formworks
Activity	The breakdown of the division into specific units of work recognised by their work capacity.	Placing rebars, pumping concrete, floor finishing
Task	The lowest recognisable work related characteristic. A combination of integrated tasks make up an activity.	Bend, pick, cut, position, lift
Elemental Motion	The basic movement that makes up a typical task.	Positive X motion, rotation about Z axis
Orthopaedics	Analysis centred on motions performed by human anatomy.	Muscle, bone, joint, tissue
Cell	Activity of the elements that make up an orthopaedics level.	Muscle tissue, nerve

Table 2. *Hierarchical taxonomy*

2.1 Hierarchical decomposition using ideal levels

The above represents a hierarchical decomposition of a construction process in relation to the way in which humans may perform their work functions. It is the belief that in practice a compromise must be obtained by which the construction task can be decomposed into its *ideal* levels; in which context the term ideal is used to express the fact that, as a result of the decomposition, the feasibility of automation and robotics can be readily identified and the information relating to their deployment can be readily extracted. On this basis, the hierarchical decomposition of figure 2 is proposed.

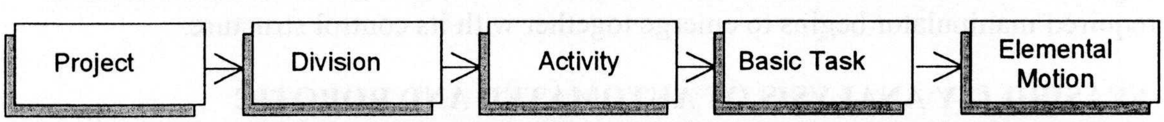

Figure 2. *Adopted hierarchical structure based on ideal levels*

Referring to this figure, at the project level information for planning and decision making can be obtained from sources such as the project specification documents, contracts, site and environmental impact analysis and CAD tools. At the basic task level suitable automation and robotic applications can be identified. Finally at both the basic task level and the elemental motion level, information becomes available to support the generation of appropriate control and command software. The decomposition within this framework then follows the path:

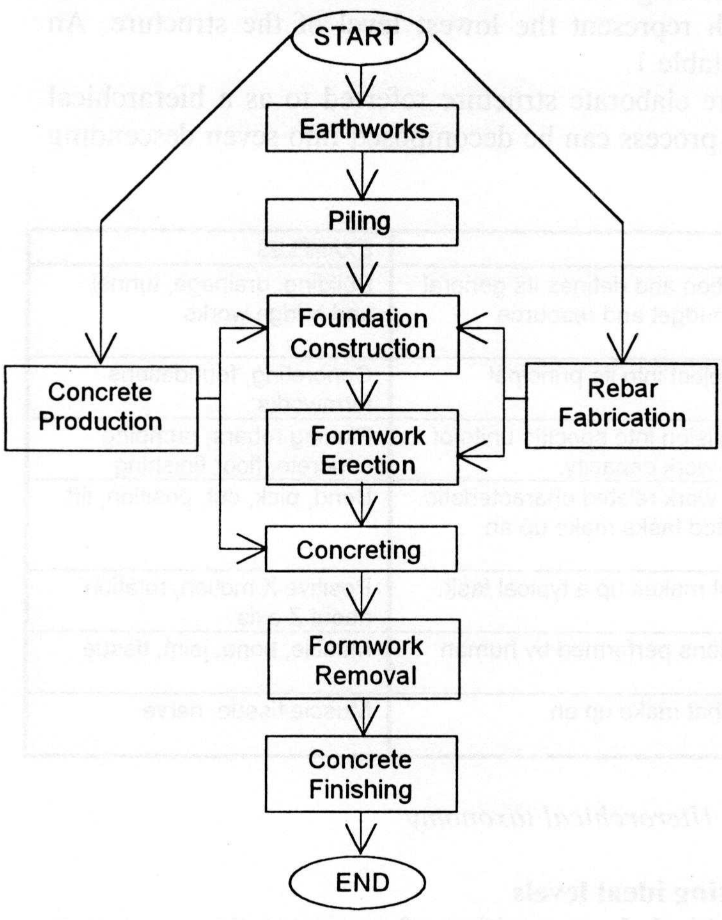

Figure 3. *Project decomposition*

- Step 1: Decompose a project into its divisions
- Step 2: Decompose a division into its activities
- Step 3: Decompose an activity into its basic tasks [3,4]
- Step 4: Decompose a basic task into its elemental movements [5,6]

The results of applying this decomposition hierarchy can be seen in figures 3 and 4 together with tables 3 and 4.

This approach to hierarchical decomposition provides a systematic breakdown of complex construction processes into a simpler set of tasks and their associated elemental motions, allowing prompt decisions with regard to the feasibility of implementing automation and robotic technologies in a particular task environment. Additionally, the analysis can be used to identify the information flows associated with each level of the decomposition. For instance, at the project level the concurrent nature of operations such as concrete production and rebar fabrication is highlighted while at the lower level the definition of the kinematic structure inherent to the required manipulator begins to emerge together with its control structure.

3. FEASIBILITY ANALYSIS OF AUTOMATED AND ROBOTIC IMPLEMENTATION OF REINFORCED CONCRETE CONSTRUCTION

Based on the hierarchical decomposition described above, the aims of the feasibility analysis are:

- To assess the extent to which available technologies are able to support the application.
- To identify those areas that have yet to receive attention.

Typical results of the feasibility analysis are presented in tables 5, 6 & 7[1].

The results of the feasibility analysis indicate the favourable realisation of automated and robotic applications in a wide spectrum of divisions, activities and tasks within a range of construction project environments. It also indicates there are areas where automated and robotic technologies are unable or unlikely to replace manual labour, for instance where there is a requirement for high levels of manipulative and other skills, space restrictions or obstacle avoidance requirements. In such cases, there is no alternative but to seek out innovative construction methods and approaches to replace existing, conventional techniques in order to facilitate the introduction of automated and robotic technologies.

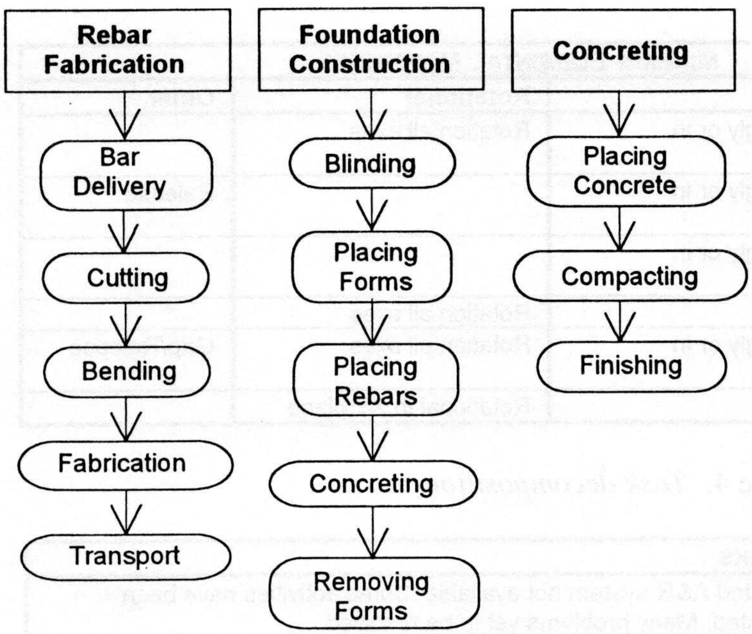

Figure 4. Division decomposition

ACTIVITY	BASIC TASKS
Blinding	Position, pour, spread *<concrete>*
Placing forms	Position, align, connect (fix) *<form>*
Placing rebars	Lift, transport, position, fix *<rebar frames>*
Placing concrete	Position, pour, spread *<boom>* *<concrete>*
Compacting	Position, vibrate, remove *<vibrator>* *<concrete>* *<vibrator>*
Finishing	Various
Removing forms	Strike, disconnect *<form>*

Table 3. *Activity decomposition*

The majority of automated and robotic devices considered were found to have the ability to replace manual labour in relation to more than one task. Others, by using different strategies, have the capability of simplifying some construction routines, for instance in the use of finishing robots. It was also noted that it is a construction norm to require the application of more than one automated and robotic device within a system to perform the function of a division or activity.

[1] The abbreviation A&R is used to replace the phrase 'Automated and Robotic' in these tables

BASIC TASK	MINIMUM ELEMENTAL MOVEMENTS Linear	 Rotational	 Other
Align	X, Y, Z directions. Singly or in combination.	Rotation all axes	
Fill	X, Y, Z directions. Singly or in combination.		Release
Hit/Strike	X, Y, Z directions. Singly or in combination.		
Mix		Rotation all axes	
Place	X, Y, Z directions. Singly or in combination.	Rotation all axes	Grip/Release
Spread	X, Y directions	Rotational in XY plane	

Table 4. *Task decomposition*

DIVISION	REMARKS
Foundation Construction	Integrated A&R system not available. Some activities have been automated. Many problems yet to be resolved.
Prestressed Precast Concrete Production	A&R technologies exist in plant, not applied in-situ.
Rebar Fabrication	An integrated A&R system has been developed and is in use.
Trenching	Some activities have been automated. Significant scope for an integrated A&R system.

Table 5. *Feasibility analysis at division level*

ACTIVITY	REMARKS
Concrete Placement	A robotic manipulator is in use with manual spreading. Scope for an integrated A&R system.
Rebar Bending	A robot rebar bender integrated within an A&R system is in use.
Concrete spraying	An A&R concrete spraying system is in service, particularly for tunnel construction.
Transport	Possible applications complicated by complex environment.

Table 6. *Feasibility analysis at the activity level*

RESOURCE	BASIC TASK	REMARKS
Concrete	Position boom Pour	Tele-operated articulated multi-link manipulator.
	Spread	Screeding robot can assist spreading.
	Vibrate Compact	Concrete compaction robot.
Form Support	Lift	Robot tower crane.
	Transport	Robot crawler crane.
	Unload	Robotic construction manipulator.

Table 7. *Feasibility analysis at the task level*

Hence it is essential to ensure that the system components are able to communicate and synchronise operations between themselves in order for the system to function effectively suggesting in turn the need for a sophisticated information hierarchy.

4. SIMULATION

Two aspects of simulation were considered, the operation of a construction manipulator in the form of a concrete placing robot and of the integrated site operations.

4.1 Concrete placing robot

based on the results of the feasibility analyses, the operation of a number of concept designs for a concrete placing robot to be used on a multi-storey, steel framed building were investigated using the simulation package WORKSPACE. The design considerations for this robot were:

- The robot should have the ability to place concrete at any location within its working envelope.
- The robot should handle all decision making in relation to its current activity.
- The robot must be able to integrate with other components of an automated and robotic system in fulfilling its function.

The resulting simulation highlighted a number of problems associated with the operation of a concrete placing robot including the need to provide both horizontal and vertical mobility and the requirement of some form of performance monitoring system to ensure that an even coverage was being achieved. The effectiveness of the functional decomposition approach in enabling the requirements of the robot to be identified and key features identified was, however, reinforced be these studies.

4.2 Process simulation

The process simulation was based on the use of MicroCyclone and DISCO [7] with a number of processes being simulated including automatic and robotic excavation, piling, formworks, and concrete finishing. While the simulation was able to provide an evaluation of the individual activities together with an indication of the performance levels required from an automated and robotic system replacing human operators, the simulation of multiple, interconnected operations with shared resources and dependencies was not possible. Similarly, the effect of different information structures on system behaviour and performance could not be evaluated [1].

5. CONCLUSIONS

Though there are now an increasing number of instances where automated and robotic technologies are being adopted within the construction industry there still remain many areas of activity where little or now progress has been made. Indeed, it could be argued that developments to date have proceeded in relation to readily identifiable areas of repetitive activity for which an environment suitable to the deployment of automated and robotic technologies could be created. If the further development and integration of these technologies within the construction process is to be achieved then it is necessary to gain a fuller understanding of the functional requirements of the processes themselves and of the required technologies.

In the paper an approach to achieving this understanding based on a hierarchical decomposition of functions is presented supported by simulation of both the manipulator and the associated process environment. Further, the need to extend current simulations to encompass the information environment and associated dependencies has been identified, possibly involving user interaction in the decision process.

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