# ADAPTING BUILDING TECHNOLOGY TO FACILITATE ROBOTIZATION

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ABSTRACT

This paper reports on the preliminary work of a research project which is looking at the extent to which modifications in basic building technology might be necessary to accelerate the progressive robotization of on-site production processes. The research programme, which is outlined, will incorporate studies of on-site processes for certain superstructure elements of factory and office buildings. A subsequent stage will assess the suitability of robots developed in other industries for dealing with these on-site processes. The feasibility of constructing a 'mock-up' working, scale model of an appropriate robot will also be studied.

## 1. BROADENING THE SCOPE OF APPLICATIONS FOR CONSTRUCTION ROBOTICS

So far, the development of construction robotics has concentrated upon well-defined production processes where tangible benefits - usually savings in production costs - are readily apparent. Typically, these robots involve the replication of manual processes within well-defined technological boundaries. By comparison, opportunities to broaden the application-base through modifications to basic building technology have received little attention. The purpose of this paper is to consider this matter in more detail: first, by outlining the programme of a recently commenced research project (Section 2); secondly, by reporting on the preliminary work in identifying likely trends in construction technology over the next 10-15 years (Section 3); and finally, by considering the ways in which these trends might influence the development of robots for on-site production processes (Section 4). The paper does not, however, attempt to specify precise changes in building technology, since this forms a later stage in the research programme.

## 2. SERC RESEARCH PROJECT

The main thrust of this two year research project is the examination of basic building technology and allied on-site production processes, and not the development of construction robotics *per se*. However, it is anticipated that a subsequent development project will use the findings from this current research programme to produce a prototype robot.

### 2.1 Aims

The aims of the current research programme are three-fold:

1. To determine the scope for deploying flexible manufacturing systems, incorporating robotics technology,

on construction sites.

2. To determine the extent of modifications to basic building technology that would accelerate the progressive robotization of on-site production processes.
3. To study the feasibility of demonstrating the results of 1. & 2. above through the construction of a working, physical model that could act as the reference point for future UK industry-based research and development programmes.

The research has adopted the following working hypothesis: robotics developed for other industrial applications can be adapted and then deployed on construction sites, but their success is dependent upon essential modifications to basic building technology.

2.2 Stages and objectives

The following work stages are contemplated, with an indication of the objectives to be met:

1. Determining the extent to which production processes can be undertaken off-site, with the object of reducing those remaining on-site to the assembly of components and their fixing in place.
2. Determining the levels of operative knowledge, skill, physical strength, mobility and adaptability that are involved in the labour intensive aspects of the on-site production processes for the superstructures of factory and office buildings; but limited to the frame, roof, external enclosure and internal sub-division.
3. Determining the levels of machine 'intelligence', skill, force, effort, mobility and adaptability that are involved in the mechanised aspects of the on-site production processes for the superstructures of factory and office buildings as given in 2. above.
4. Examining the basic building technology used in factory and office buildings to determine the extent to which changes might have to be made to accelerate the deployment of construction robotics.
5. Evaluating the capabilities of robotics technologies used in the automotive, marine engineering and nuclear power industries and determining their suitability for adaptation for use within flexible manufacturing systems on construction sites.
6. Undertaking a study on the feasibility of constructing a working, scale model of an example building, focussing upon one superstructure element as the basis for illustrating the extent of the changes in basic technology that would be necessary to exploit the robots identified in 5. above; that is, to identify the problems of automating a particular fixing process and indicating the likely solution.

2.3 Timing

The research work, which has recently commenced, is examining present and likely future developments in construction technology, especially in materials and components manufacturing. This work forms part of Stage 1.

above and will be completed within the next few months.

Stage 5 is to be left until as late as possible in the programme of work so that it might take account of the latest advances in robotics.

As stated above, Stage 6 involves a feasibility study for constructing a working, scale model of an example building, focussing upon one superstructure element; for example, cladding for external enclosure. Clearly, in the timescale covered by this programme it would not be possible to construct an actual working model. This work is a highly skilled and specialised task, and to attempt to undertake it within the time available is not feasible. Therefore, this stage will be limited to examining the feasibility of constructing such a model. Some initial research has already been undertaken to explore the work in constructing a model. Preliminary estimates indicate that the design and construction of a plausible model with a real small scale mobile manipulator, and a frame-climbing and cladding-fixing robot would take approximately twelve months.

## 3. TRENDS IN CONSTRUCTION TECHNOLOGY

Construction technology can be sub-divided, for the purposes of this paper, into building technology, and engineering services and fitting out.

### 3.1 Building technology - a static target

Basic building technology has changed little over the centuries and is well understood, with knowledge about it easily transferred from one generation to the next. By its very nature, traditional building constitutes a relatively stable technology representing a static target for the development of construction robotics. Such stability is essential, as the time needed to move from the concept stage to the realisation of a working robot could be at least five years. Even minor changes in the underlying technology of the target application could mean that the robotic solution was itself technologically obsolete before it could be usefully deployed on construction sites.

Changes in building technology - where they are occurring - are at a rate which the industry can handle. Clearly, new materials and components necessitate change and are responsible for introducing more and more specialist contractors into the industry. However, there will be few radical changes, if any, over the next 10-15 years in basic building technology (1). Even so, it is likely that less and less manufacturing will take place on site once the substructure is in place. Generally, there will be a shift in the manufacture of superstructure components from the site to the factory where flexible manufacturing systems will enable greater variety, lower production costs and increased quality control to be achieved.

Superstructures will become component assemblies, with cast in-situ concrete accounting for a lower proportion of structural frames as time passes. In-situ concrete is, however, a very versatile material and so is likely to remain competitive - both in terms of cost and time - alongside structural steelwork and pre-cast concrete. Of course, superstructures involve more than structural frames, floors and stairs and it would be unwise to concentrate on core elements alone. Cladding, which forms a significant part of most new buildings in terms of its cost and resource requirement, is an area where mechanisation and, therefore, robotization seems likely.

Superstructures already represent less than one half of the capital cost of many new buildings. Therefore, the scope for construction robotics to influence the overall cost and pace of construction may be limited to this (potentially) reducing proportion of the total building project. However, that is not to say it will not remain significant in capital terms.

3.2 Engineering services and fitting out - a moving target

Engineering services and fitting out involve technology which is moving rapidly. Furthermore, such technology can easily be dominated by a small number of high value materials and components involving comparatively modest levels of labour. In some cases, the capital cost of engineering services has increased from 20%-30% of the total building ten years ago, to over 50% today. When the cost of fitting out works is added this cost can easily reach 60%.

The next 10-15 years is likely to see much greater modularisation of components within engineering services as one-off designing for specific uses is replaced by flexible servicing. This will involve short life plug-in components which are likely to be replaced frequently. There will also be a move towards high quality finishes in many new buildings, with an increase in dry, rigid components made from new materials. As a result, the integration of services and finishes will have to be more closely managed. This will lead, in some cases, to contractors offering a complete package for the fitting out of the interior of 'core and shell' building projects.

3.3 Rationalisation of design and construction

Rationalisation of design and construction is needed even without robots. To take manual tasks and automate them exactly is to assume that the task to be performed is entirely satisfactory as presently performed and that it can occur independently at any time. Clearly, few if any tasks would fall into these categories. Indeed, many tasks are performed in the way they are because of limitations in the capabilities of operatives; for instance, physical strength and manual dexterity. Therefore, no attempt should be made to replicate manual tasks until the limitations inherent in the manual performance of these tasks have been uncovered. This is hardly a new idea and, indeed, several researchers have already highlighted this need (2),(3).

Many construction operations are still predominantly craft-based, although the use of new materials and components has deskilled some operations. Traditional craft skills remain in demand and where they are in short supply they command a premium. Naturally, this has stimulated interest in the development of construction robotics to supplement or replace these skills. Additionally, some craft skills are even being displaced by artefacts which recreate the style and appearance of traditional technology. Innovation has been greatest here, with successive deskilling of on-site production bringing tasks down to the level of simple assembly and fixing operations. Nevertheless, labour can be extremely mobile and adaptable, and even economical. The nature of most present day designs is clearly well suited to labour intensive production processes, even though mechanisation is prominent in many areas. It is reasonable to assume, therefore, that designs which are intended to take account of construction robotics will have to be different to those that use traditional craft skills.

Thus, any examination of current technology must involve both design and construction implications. But since robots are production aids, such an examination must commence with a close study of on-site production processes. From this point it would then be appropriate to move progressively upstream towards early design. In other words, feedback of design and construction information must occur (2).

Simplifying building technology and allied production processes to accelerate progressive robotization can be thought of as a natural extension to the principle of constructability; ie. designing to facilitate construction. This could begin with the incorporation of management techniques such as construction planning (using feedback from productivity studies) during early design. These would help to identify areas where changes to design are needed. This could extend to the use of particular combinations of materials and components which were especially amenable to robotization.

## 4. DEVELOPMENTS IN CONSTRUCTION ROBOTICS

### 4.1 State of play

For the purposes of this paper, construction robotics can be said to fall into two categories: first, machines that are aimed at a task specific application and which perform under tele-operated or computer programmed control; and secondly, those robots that would embody intelligence which would enable them to respond to, and learn from, the environment around them.

Robots in the first category include the much publicised Japanese examples of concrete finishing and grinding, sprayed fireproofing, steelwork positioning and rebar placing (4). These mainly second generation robots represent the state-of-the-art. The manual tasks which they endeavour to replicate are well-defined (or well-structured) and contain relatively high levels of repetition. These robots operate within controlled environments only and may not be easily adapted to other forms of building technology and allied production processes. In other words, they are dedicated robots, designed to fit within existing technological and production boundaries (or contexts).

Robots in the second category are generally those that might be termed advanced or autonomous, being endowed with some degree of intelligence which will allow them to perform a variety of complex, ill-structured tasks (5). Of course, no such prototype yet exists, although major research and development initiatives in Japan, USA and within the EC have begun and are reported elsewhere in this volume.

Thus, construction robotics could be said to fall into two distinct categories: dedicated, second generation robots and advanced or autonomous, third generation robots. Additionally, autonomous robots are likely to be modularised in that their functionality could be changed by reconfiguring basic systems and mechanisms such as delivery, sensing and analysis to suit the special circumstances of the task(s) to be performed.

Construction robotics may well be limited at present to a dozen or more prototypes dedicated to task specific applications, but they will eventually become commonplace on construction sites. In the same way that designers will have to come to terms with CAD as a design tool - as opposed to just a draughting aid - so too will constructors have to integrate robots into their on-site production processes. But the analogy goes even further. Present generation CAD systems are aimed at speeding up the rate at which production drawings are produced. They are draughting workhorses that embody no intelligence. Real computer-aided design can take place only after architectural KBES have been successfully developed. In much the same way that computer-aided draughting is a limited improvement over the manual alternative, the dedicated floor finishing robot is a limited improvement over the operative armed with a float. Neither represent the ultimate solution, but just one step in the progression towards total automation and robotization (6).

4.2 The future

It is not surprising that there should be considerable interest in intelligent robots that would be capable of executing a variety of complex, ill-structured tasks (5). The reality is, however, that practical achievements to date have been in tackling simple, well-structured tasks (4). Indeed, a parallel can be drawn with the state-of-the-art in KBES, where the problems addressed are largely of a trivial nature (7). Here, the boundary of the knowledge domain must be drawn precisely and the knowledge itself must be well-structured. Robots that embody intelligence must likewise be domain specific, with the boundary of knowledge equivalent to the technological and production contexts within which it is expected to function.

There would seem to be two development tracks for on-site production robots:

1. Intelligent or advanced robots that can execute complex, ill-structured tasks.
2. Dedicated, present generation robots executing discrete tasks, but operating on simplified building technology.

These two tracks are not mutually exclusive. They represent complementary developments that should result ultimately - through their convergence - in the widespread availability of on-site production robots. Indeed, the progressive robotization of discrete tasks will eventually reach a critical level, where total automation of on-site production processes becomes a reality (6). The pace of change can be accelerated by adapting existing robots (8), but the tasks to be performed must be simplified, by modifying the underlying construction technology.

5. CONCLUSIONS

It is easy to be impressed by the potential of construction robotics, so much so that total robotization of on-site production processes might seem feasible within a 10-15 year horizon. Robots may well be capable of automating many tasks falling under the building technology umbrella, but these tasks represent just a part of the total tasks to be performed on a modern building project. They may also represent less than 50% of the capital cost of such projects. Therefore, the potential for robotics as far as on-site production processes are concerned must be put into perspective.

The preliminary work of the research project described here would indicate that building technology needs to be examined and modified if the full potential for on-site construction robotics is to be realised. Furthermore, the underlying construction technology of the target application needs to be stable (or near stable) if substantial research and development effort is to pay off. Traditional building technology is relatively stable and, if anything, is moving towards a simplified assembly and fixing scenario, using dry, rigid forms of construction. Radical changes in the type of basic materials and components are unlikely in the next 10-15 years, but there will be a shift in the particular combinations of these materials. Even so, this technology is accounting for a steadily declining proportion of the capital costs of construction. There is therefore a limit to the extent to which construction robotics might influence on-site production processes.

Furthermore, engineering services and fitting out represent a substantial proportion of the cost of many new buildings. The underlying technology is characterised by innovative materials and components, most of which are high value by comparison to materials used in basic building work. Labour may still account for a significant proportion of cost, but involves highly specialised skills that are subject to constant change as the technology becomes more sophisticated.

A possible scenario for the future would be for buildings to have their 'cores and shells' constructed almost entirely by construction robotics using fairly traditional building technology based on mostly dry, rigid materials and components. Engineering services installations would be largely pre-fabricated off site and in this way could be partially commissioned before fixing in place. Pre-finished components for fitting out would still require significant levels of labour, albeit with increased mechanical assistance using robots for positioning and fixing.

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