AUTOMATION AND ROBOTICS:
THE DESIGN AND OPERATIONAL PLANNING OF
CONSTRUCTION PROJECTS

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ABSTRACT

The potential for robotic assembly in construction is examined with particular reference to the evaluation of the building design. The broad issues of design for construction assembly are explored and the relation to manufacturing assemblies identified. The paper presents the idea of representing the building design in a generative way determined by a rule system derived from the spatial relations among building components. It is argued that this provides the means to evaluate designs based on (1) component features appropriate for automatic mating and assembly, (2) component and subassembly delivery and (3) construction planning for effective use of assembly resources. The main conclusion is that the availability of automatic assembly will necessitate a radical revision of building design processess.

1. INTRODUCTION

Design for assembly has become a standard phrase in Manufacturing Automation and forms part of a general theme which attempts to create the relationship between design and production in manufacturing. This concept is equally applicable to construction although traditionally design and production are divorced.

There are many difficulties with implementing design for assembly which manufacturing research has addressed (1,2). The main approaches have emphasised the rationalisation of assembly moves, particularly directions of assembly moves, the types of fixing employed after mating and the detailed design of the mating components to guide assembly by contact forces.

A separation of the global and local aspects of the problem can be observed in this approach. The design of components mating emphasises the local aspect with automatic assembly devices and their supporting sensing systems, guiding components through a sequence of locally constrained moves to achieve final placement. The constraints are essentially kinematic in nature and the problems centre around the ability of the assembly device and associated sensing system to respond to spatial constraints and to recognise when goal spatial relations have been achieved.

2. DESIGN FOR ASSEMBLY

To improve design for assembly it is necessary to be able to analyse the consequences of design decisions at both levels. It is proposed here that appropriate methods of constructing the design be adopted which either guarantee the requirements for automatic assembly or can be guided by the requirements for automatic assembly. The construction of designs according to rule based generative schemes offers the potential to realise this aim (3,4,5).

The recognition that component features and partically completed designs are central to a design description forms the basis for current approaches to CAD. The attention to features will lead to understanding during the design process of the complexity and difficulty of mating. However, it will not necessarily contribute to understanding the aggregation of these features which form the spatial context for planning the assembly sequence and the types of approach move required (6). Features based CAD requires augmentation by rule based approaches to the aggregation of features to create the final design. In the case of assemblies which are aggregates of features across several components, the developing relationships among features across many components becomes central to the task of planning assembly moves.

Design for assembly must thus be based not only on the local mating of features but also on the relations of features across the design. In this way the spatial context of assembly is determined and the information required for assessment of motion planning made available. The nature of assembly design rules should thus encapsulate the requirements for rationalised assembly operations. A route to this goal is to consider the design rules as mirroring assembly actions. Designs will be created by sequences of constructive rules which act at the component level to bring together features and then act at the subassembly level to bring together aggregates of features. The design is thus described as a sequence of rule applications based on the spatial relations between features and components. Hovever, there still remains the central problems of inferring the features of components and subassemblies which emerge from the rule applications but are not specified explicitly in the rules. It is these emergent spatial relations which provide the context for assembly operations.

The scope for systematic and rule based design systems which can encapsulate assembly knowledge is considerable. The opportunities provided by the construction industry are particularly significant in this area as it is a largely an unautomated activity of considerable size, exhibiting complex material and component delivery problems as well as the mating and fixing problems associated with a wide range of components. A major lesson from manufacturing assembly is that without fundamental attention to design for automatic assembly there is a tendency to move towards reduced cost or easily manufactured components at the expense of being unable to assemble automatically. The building design is a complex spacial assembly characterised by its static, evolving nature. Assembly operations take place inside and around the current state of the building structure. Assembly 'stations' are moved around the partially completed structure. Access and emerging features are critical in building design. The robot assembly device will be intimately linked with the building structure. This emphasises the need to examine design for assembly in parallel with the development of assembly automation. The design and construction sequence will determine the possibility for automatic assembly to a greater extent than component design for successful parts mating. It is argued that the design of the building must be understood in terms of a developing assembly of components which form the spatial environment for these assembly operations. The building design description required to plan and assess automatic assembly is thus not static but phased and sequential. The rule based descriptions indicated above for manufacturing assembly appear to have particular relevance for building design.

The planning of the construction process requires the transport and fixing of large numbers of parts. The design process has tended to emphasise the compositions of these parts in terms of functional relationships to satisfy functional specifications such as support, weather protection, lighting, heating and ventilation. Construction planning emphasises the sequence and spatial relationships of these components as they are brought into place on site. The ability of design systems to exhibit knowledge of these construction sequences would be a great advantage in planning for automatic or robotic assembly. The designer should be aware of the spatial relations required between features and the spatial context in which they are to be realised. If it were possible to make these spacial relationships an integral part of the means of design then rules could be constructed based on these spatial relations. Constructive rules to implement defined spatial relations then form the basis for creating building designs and would open the way for a systematic link between building design and construction planning. The spatial relations between components are now the central units of the design. The developing building during construction then corresponds to the developing design as rules of construction are applied.

3. MODULARITY

A criterion often applied to design for assembly especially in flexible manufacturing assembly is modularity. This may refer to the use of similar components, components within a modular dimensional system or the use of subassemblies common to different final assemblies. The complex spatial nature of the developing building can be considerably simplified if the component assemblies obey a system of dimensional co-ordination. Not only are the local operations of handling, mating and fixing simplified but also the determination and updating of the spatial properties of the developing building.

The concepts of modularity can be effectively put into practice using rule based generative design methods. The selection of design rules based on the spatial relations between a vocabulary of modular components will ensure resulting modularity in the developing and final design. The modularity may thus be incorporated into design generation rather than made an imposed constraint on the design. This can avoid a cascading process by which small local changes made to ensure modularity have an effect on the whole design in potentially drastic and unforseen ways. Traditional modular schemes are often considered to impose undue constraint on design. This is caused by the concentration on component modularisation, without the formal representation of the possible ways that the components can be assembled. Modular ways of relating components contained in constructive design rules will ensure the dimensional coherence of the whole design and provide the freedom from the apparent constraint imposed by modular components. Modularity and dimensional co-ordination across disparate elements of the building is essential for simplifying assembly and for planning the sequence and hierarchy of assembly operations. Further, effective planning for robotic assembly across building projects will be facilitated by the adoption of agreed systems of dimensional co-ordination and component tolerances.

4. COMPONENT DELIVERY

Planning robotic assembly deals not only with the assembly itself but also with the presentation and delivery of components to the assembly system. In manufacturing this aspect of automatic assembly is not directly concerned with product design. However, for construction assembly this becomes a critical area of the design. Components need to be delivered to locations within the building. The geometry of constaints and supports afforded by the current building state needs to be understood at each stage. The building structure itself may be used as the basis for component transport and delivery. Building design must consider how developing geometry affects material transport. These considerations range link between the two descriptions is needed to effect integration of design and construction. Expressed in a different way, the translation is required between the formal languages derived from separate rule systems to provide the interpretation of architectural design as construction procedures.

6. CONSTRUCTION PLANNING

The main thrust of the paper has concentrated on the need for means to represent the developing building so that construction operations, particularly assembly can be planned effectively. The use of such methods may only have a manual effect on the functional and aesthetic features of the building, but there will be a significant impact on the nature of the building structure and the design of components to facilitate automatic assembly. Design for assembly in construction must consider not only potential construction plans but also the precise details of those plans in order to make adequate evaluation of the overall use of construction resources, whether robotic, machine or manual. To this end, attempts are being made to link computer based production systems (9) with CAD systems. These integrated models should allow problems to be formulated in a more rigorous manner than hitherto and provide solutions that have not previously yielded to manual methods. Although the design may be suitable for robotic assembly it is possible that further evaluation shows that time and cost far outweighs any advantage in labour saving or quality. It is important therefore that effective methods evaluating generated construction plans and making iterative improvements are available. Time and cost implications must be fully explored for any construction plan and every effort made to optimise the relationship of these two parameters (10).

More significantly, a major problem relates to the variability of construction sites and site layout case studies are being analysed. The main planning features identified are movement, storage, activities, access and control with particular attention given to movement and action density in the various activity flows. It is important that on all sites a central focus or series of central focuses about which all activities will revolve is determined . In other words the "centre of gravity" of each particular structure is determined around this focal point. All other operations in that area can be co-ordinated geometrically for the site to produce a common centre of gravity which becomes a focus for all operations. In particular the point of access will influence the focal point. It must be remembered once again that this will not be static but will change with the dynamic nature of the activities involved.

7. ROBOT PLANNING

The creation of an evaluated construction plan identifies robotic requirements where appropriate and necessary. The broad feasibility based on design geometry of robotic assembly will be established. However, the problem still remains of planning robot actions to realise the spatial relations between components as specified in the design rules. The power of the rule based approach to building design is significant at this stage. Motion plans are constructed within the current building geometry for each stage for construction. The spatial environment for the robot, when moving and handling components, is derived from the corresponding design description for that stage of construction. The detailed programmes of assembly moves are now constructed and requirements for sensor guidance and navigation specified. At this stage it may be appropriate to leave the local planning of the assembly moves to the execution phase of the robot task. The nature of the construction site may demand this separation of planning and execution since it may be difficult to forsee all contingencies in constructing the assembly plan. Given an inherent uncertainty in the construction enviroment it would be misplaced effort to attempt detailed planning of robot moves before the corresponding stage of construction is reached. The requirements of rule based design which have been proposed as appropriate for creating building design in such a way that can capitalise on the advantages of robotic assembly and for which effective construction plans can be generated to make optimal use of construction resources, will impose particular needs on the nature of CAD systems used in architectural design and construction planning. Architectural CAD has generally used a formal modelling framework based on geometric elements for entering, recording and displaying the spatial features and characteristics of the final design or significant subassemblies. The process of creating such models involves the informal application of design rules structured according to levels of detail and types of building service.

8. CONCLUSIONS

Design evaluation for construction planning and assembly methods should be accommodated within the design process and guide design generation at each stage. The argument is that a new approach to design is required. Autonomous robotic machines require appropriate design descriptions of the building to make available the necessary information about the developing geomtry of the building as work progresses on site. It is proposed that Rule based methods based on assembly operations of components on site provide the foundations for this new approach.

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