DESIGN FOR AUTOMATED BUILDING ASSEMBLY

C F Earl
Department of Engineering
Bristol Polytechnic
Frenchay, Bristol, BS16 1QY
United Kingdom

ABSTRACT

The creation of building designs is examined in the context of increasing potential for automation of assembly processes. The general requirements of design for constuction assembly are identified. The paper explores the potential for bringing the design and assembly operations into closer relationship by the use of generative methods of design. These generative methods are based on the spatial relations in the building assembly which are realised in its construction. This allows for component designs to exhibit features appropriate for automatic assembly as well as enabling evaluation for component and subassembly delivery. The paper concludes that the extensive benefits resulting from construction automation may be better realised with rule based methods of design.

INTRODUCTION

Manufacturing automation has emphasised the importance of the relationship between design and manufacture. In particular the difficulties of assembly automation, particularly when required to exhibit flexibility, has led to close attention on design for assembly. This involves, in general terms, the relation between different knowledge representations for geometric description and process description which forms the basic model for CAD-CAM systems.

Manufacturing research has addressed some of the difficulties of design for assembly [1,2]. The two aspects commonly emphasised are the rationalisation of assembly moves, particularly the directions and types of assembly moves, and second the detailed design of the mating components to guide assembly through the contact conditions arising through the process of assembly.

These two aspects reflect a division of the local and the global components of the problem. The design of components for ease of mating emphasises the local with automatic assembly devices and their supporting sensing guiding components through a sequence of locally constrained moves to achieve final placement. The constraints are essentially kinematic in nature. The problems centre around the ability of the assembly device and its associated sensing to respond to the sequence of spatial mating constraints to achieve goal spatial relations between the components.

The rationalisation of assembly moves emphasises the global aspect with attention to assembly task planning, collision avoidance and robot path determination in the approach moves to mating as the major factors. The overall context of the assembly approach moves, before the local conditions of mating are encountered is the focus of this area of design for assembly. This rationalisation may be further extended to include the presentation of parts, moves to acquire parts from feeders and the determination of orientation in the robot gripper so that the mating moves can proceed to successful conclusion.

The two aspects correspond to distinct robotic problems. The first is characterised by sensor based moves responding to local conditions whilst the second requires the extensive planning of the whole assembly operation. The concerns are typically the order of component placement, occlusion and path planning.

DESIGN FOR ASSEMBLY

To improve design for assembly it is necessary to analyse the consequences of design decisions at both levels. In the case of automating construction assembly operations both aspects assume an increased complexity over the manufacturing area. The components and subassemblies exhibit complex mating requirements and the spatial environment in which the assembly components are delivered and manipulated into position is often ill structured and constantly changing. These difficulties lead to the requirement for a more comprehensive method of relating design and assembly operations than is currently available for manufacturing assembly.

It is proposed here that appropriate methods be adopted for describing the design which take into account at design stage the requirements for automatic assembly. The constuction of building design descriptions according to rule based generative schemes offers the potential to realise this aim [3,4,5].

The recognition that component features and partially completed designs are central to a design description forms the basis of current approaches to CAD. The attention to features will lead to understanding during the design process of the complexity and difficulty of component mating. Various features and combinations of features can be identified with particular classes of assembly operations and corresponding robotic and sensing requirements. However, it will mot necessarily contribute to the understanding of the aggregation of these features which form the spatial context for planning the assembly sequence, parts delivery requirements and the transfer of components to their assembly locations [6]. Features based CAD requires augmentation using rule based approaches to the aggregation of these features to create the final design or partially completed designs. The developing relationships among features across many components and the composite features created as the design takes shape become central to the task of planning the assembly moves.

This attention to higher level composite features and relations among spatial features across the design imposes a requirement to control and guide the application of assembly design rules. These should encapsulate the requirements for rationalised assembly operations.

A route to the goal of creating design descriptions relavant to evaluating designs for automatic assembly is to consider the design rules as mirroring assembly actions. Designs are 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. However, there still remains the central problem of inferring the features of components and subassemblies which emerge from the rule applications but are not specified explicitly as part of the rules. It is generally these emergent features which form the spatial context for the assembly operations.

Manufacturing assembly has gained considerably from the movement towards flexible automation and robotic asembly methods. Attention is focussed on production requirements as well as functional design. Designs have been rationalised and improved, leading to lower assembly times, better quality and greater consistency. This has resulted mainly from the increased attention given to the assembly process as the assembly operations need to be specified in detail, rather than be left to interpretation by manual operators. The problems of manipulative complexity, sensing and uncertainty which robotic solutions raise prompt close attention to their reduction by appropriate design.

The scope for systematic and rule based design systems which can encapsulate assembly knowledge is thus large. Attention in design for assembly should now shift to the design process and how this can be controlled to produce designs possessing the necessary characteristics for automatic assembly.

The opportunity provided by the construction industry is particularly rich in this area as a largely unautomated activity of considerable size, exhibiting complex material and component delivery problems as well as the mating and fixing problems of a wide range of components. A major lesson from manufacturing assembly is that without fundamental attention to design aimed specifically 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 construction industry is in the position to attend to the problems of design to facilitate the quick and effective introduction of robotic assembly methods. Important revisions of the ways that buildings are designed is needed so that the potential for automated assembly is optimised. The building design is a comlex spatial 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 stucture.

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 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 spatial relationships form an integral part of the means of design then constructive rules to implement defined spatial relations 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.

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 coordination. 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 effectivley put into practice using rule based generative design methods. The selection of dsign 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 a 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 coordination 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 coordination and component tolerences.

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 constraints 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 from the need for additional delivery structures to the evaluation of component access to the site of assembly. Component routing and access will be dynamic as construction proceeds and effective construction planning needs kowledge of how the building geometry will evolve on site.

The concepts of rule based design provide the basis for considering the dynamic geometry for component access. Explicit requirements can be placed on the generated designs to ensure adequate access for both components and assembly equipment. These constraints will affect the type and sequences of rule applications and provide the means to control design generation as well as forming the basis for creating material delivery plans. The major difficulty encountered at this stage is that complex spatial conditions need to be recognised in the developing design which are the consequence of composite rule applications in different areas and at different levels of detail in the design. The inference of emerging spatial properties is a critical problem.

The design of assemblies has often attempted to group components into functional subasseblies. This design principle has application to building assembly by the use of subassemblies prefabricated on or off site. The potential advantages in factory based prefabrication resulting from a simplified working environment need to be set against the spatial access and fixing problems for the complex subassemblies. The evaluation of relative merits poses a significant problem for the construction planner and for the methods of rule based design proposed. Effectively there are two assembled systems, both generated by sequences of rule applications and both with complex aggregates of spatial properties. Ensuring access, transport and handling requires mutual interaction between the two generative schemes and the emergent spatial relations they create.

ARCHITECTURAL DESIGN AND BUILDING ASSEMBLY

The use of rule based design in building is not confined to rules corresponding to physical assembly operations. The arrangement of spaces within the building can also be generated by rule systems [7,8]. The rule applications are then not explicitly concerned with the building construction but rather its spatial structure and architectural style. The rule sequences take no account of constructional principles and serve to create spatial aggregates which meet functional and aesthetic specifications.

The architectural and constructional modes of considering building design thus have a common formal base when considered in terms of rule based design systems. This should provide the opportunity to integrate the two approaches so as to provide the architect with the formal tools needed for spatial design and the construction planner with the formal tools for operational design of the building for on site assembly. Both methods describe the same spatial composition but in different ways. The 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.

CONCLUSION

Building design using rule based systems which reflect the assembly process offers the scope to create building descriptions which enable effective use of automatic and robotic assembly methods. Further, it allows designs to be evaluated for automatic assembly and construction seqences generated which consider the developing geometry of the spatial and physical support environment for component transport and delivery to the site of assembly. The application of generative methods to architectural descriptions integrated with assembly based construction descriptions provides a powerful methodology for design for assembly in building.

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