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Construction Cladding Joining Methods: A Guide to Design for Automatic Assembly

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Abstract

One of the fundamental lessons learnt by manufacturing industry was that assembly tasks must be redesigned to suit the strengths and weaknesses of machines vis a vis human workers. The basic principles of *Design for Automation* and *Design for Assembly* can be applied to construction tasks in order to improve productivity either by simplifying existing tasks or by integrating machines with processes in a more structured construction system. This paper outlines some of the design principles which have been used successfully in manufacturing industry and applies them to the different processes which are found in the majority of industrial joining methods.

1. INTRODUCTION

Previous research into the use of automation systems for the cladding of buildings led to the design and simulation of a prototype erection device[1]. The research highlighted the necessity for components and processes used in the assembly of the facades to be designed for automation systems[2][3]. The research also showed that the methods used for joining were primitive and likely to prove troublesome for machines. Alternative methods for joining are therefore being investigated with the aim of identifying useful technologies for construction automation[4][5].

Other research has shown that construction automation requires a detailed analysis of both the task to be performed and the context in which it will be used[6]. This implies that the elements of the construction task will need modification to suit the peculiar needs and requirements of automation[2]. The principles which are embodied in "Design for Automation" closely resemble what is known as "Buildability" in the UK construction industry. Designers are encouraged to avoid difficult or complex details to improve the accuracy and speed of construction[7]. Experience has shown that applying "Design for Automation" to existing assemblies leads to improved productivity and fewer errors even when automation systems are not used[8].

Many of the techniques used in construction for joining parts on site have remained unchanged for decades and are labour intensive[9]. The use of construction automation will lead to the introduction of new techniques and methods which place more emphasis on machinery. While many of the joining methods which might be used by automated systems on construction sites are used routinely in manufacturing industry, conditions on site are different to those which are found in factories. It follows, therefore, that many of the joining techniques which may be considered will be unsuitable for use on construction sites[10].

The principal aim of this paper is to give designers of cladding fixing systems a systematic framework which will help them assess the difficulty of using different joining systems for automated cladding. To this end, the underlying principles of "Design for Automation" will be discussed in the context of cladding fixing systems. After this, the stages which are common to all joining methods will be reviewed before the guidelines for assessing the utility of particular methods are presented.

2. PRINCIPLES OF DESIGN FOR AUTOMATION

Previous research into high volume manufacturing has already defined the basic principles of "Design for Automation"[11]. These principles will be discussed in the following sections with a particular emphasis on cladding.

2.1 Combine Functionality of Components

Fewer assembly operations are needed if the functionality of several items are combined into one or two components. However, problems may arise with fabricating the new components as some materials may be less ductile or malleable than others.

2.2 Modular Design Philosophies

The use of a modular design philosophy such as Group Technology[12], can widen the applicability of automated fixings to many different cladding types. This will increase the attractiveness of automated solutions since the range of cladding types that can be erected is extended.

2.3 Reduce the Number of Fasteners

A distinction can be made between site fixings and factory fastenings as the latter are simpler and more reliable. As outlined in Section 2.1, parts can be designed to incorporate many of the functions of fasteners so that they can be pushed together without the need for special joining devices and operations.

2.4 One Operation at a Time

The complexity of the site automation systems are reduced if the need to handle several components simultaneously is eliminated. In general, assembly plans which are sequential require simpler equipment and can be carried out more quickly.

2.5 Simplify the Part Motions

The robot motions necessary to place and fix components should be as simple as possible. If a component can be inserted into an assembly along one axis with no extra rotations or sideways movements, then the robot moving the part can be simpler than one which is capable of performing complex motions within the assembly.

2.6 Improve Quality Control

Strict quality control must be enforced so that assembly errors do not arise from defects and tolerance problems. Component tolerances must be checked to ensure that suppliers comply with agreed limits, as any delays caused by incorrect manufacture will have implications for erection times and hence profitability.

2.7 Design Specific Delivery Mechanisms

In factories, feeders are used to ensure that parts are presented with the correct location and orientation. They also ensure that the parts are waiting for the robot while an assembly is in progress, not vice versa. Such mechanisms should also protect components so that they are less likely to be damaged.

2.8 Reduce Ambiguity in the Assembly

The assembly should be designed to ensure that components are assembled correctly on site. Splines or keys can be added to make it difficult for parts to be forced into the assembly. Clear and concise instructions are also necessary to enable site operatives to check that the automation systems have functioned correctly.

3. CHARACTERISTICS OF JOINING METHODS

In order to assess the complexity of different joining methods, an analysis must first be made of their constituent processes. The principles of "Design for Automation" can then be applied to the subtasks in order to automate the joining method as a whole. Some typical joining methods are given in Table 1, which also includes an assessment of the relative importance of each method in different sectors of industry. It is apparent that there are some methods which are used in manufacturing industry but which are not used in construction. This will be due partly to conservatism in the industry towards new materials and methods, but will also be related to the necessity for changing current working practices to suit the new construction technology and methods.

Table 1
Usage of Fixing Types by Sector of Industry

Fixing Type	Ae	Au	Co	Mn	Sh
bolts	C	C	C	C	C
rivets	C	C	C	C	C
screws and plugs	C	C	C	C	R
"push fit" connectors	C	C	R	C	R
deformation fixings	C	S	R	C	R
ties and chains	N	N	S	N	R
clamps	R	C	S	C	R
stitching and staples	N	N	R	S	R
welding	C	C	C	C	C
pressure welding	R	R	N	R	S
brazing and soldering	R	S	N	R	N
adhesion	C	C	S	R	N
grouting and in situ concrete	N	N	C	N	S
freezing	N	N	S	N	N

Key: **Au**: Automotive, **Mn**: Manufacturing, **Ae**: Aerospace, **Sh**: Shipbuilding and Offshore, **Co**: Construction

C: Common **S**: Special **R**: Rare **N**: Never

3.1 Basic Operations in Fixing and Joining

From a further analysis of the joining methods given in Table 1, it emerges that the joining of construction materials together on site is essentially a threefold process of positioning, fixing and protecting[5]. These three areas further decompose into six discrete stages which are always present in any joining method. However, some methods may combine several stages into a single process. What is important is the ease with which the different stages can be performed and the degree of accuracy that can be obtained in aggressive and inhospitable site environments. Each of the six stages in the joining process that have been identified will be discussed in the following sections.

3.1.1 Preparation of Components

Some joining methods require little or no preparatory work, whereas others require high degrees of cleanliness between the faces which are to be joined. For example, adhesives and welds will often not "take" in the presence of rust, water or oil.

3.1.2 Assembly of Components

After preparation, the components can be transported to the assembly point. In a factory, conveyor belts and jigs ensure that components arrive at the assembly point in the correct position and orientation, but on a construction site there is much less control. An allied problem is that of close alignment and positioning of the components relative to the building. Uncertainty in the global positioning of components is one of the fundamental problems of automating cladding assembly tasks on site. This is due to the fact that construction tolerances are much larger than those allowed in factory production methods. For example, tolerances of between 15 and 25 mm are common in structural frames of insitu concrete, whereas the cladding components are typically manufactured to tolerances of 5 mm[13]. Overcoming positional and dimensional uncertainty either involves ingenuity in altering the assembly methodology, or it requires the use of expensive sensing systems to compensate for the lack of firm knowledge about the environment.

3.1.3 Mating of Assembly to Fixing Device (or vice versa)

During the course of the fixing process, the components and machines must be brought together and then prepared for use. In a factory setting, the assembly travels to the fixing device or to a known point in space to which the fixing device can be moved. By contrast, on a construction site, all of the positions and orientations are defined relative to features in the partially constructed building.

3.1.4 Initiation of Fixing Process

Once the fixing device has been positioned correctly, some sensing may be required to ensure that the fixing process progresses satisfactorily and that there are no problems which might cause the fixing to be aborted. A specialised fixing unit can be attached to the robot in advance, which adds to the complexity and cost of the robot but which eliminates some local sensing.

3.1.5 Withdrawal of Machine After Fixing

This is a simple operation but may become complicated if the fixing has to be aborted. It is unlikely that a simple reversal of the fixing operation will lead to a proper removal of the components, since the fixings may be damaged in the process. If the fixing is completed successfully and needs no further attention, the fixing device may be moved to the next location.

3.1.6 Post fixing Operations

Some of the processes used in manufacture require extensive testing and finishing before they are considered to be complete. Welding and adhesives are obvious examples, but checking of correct bolt torque is also important. Other operations such as painting or rustproofing may be necessary as well as nondestructive tests.

4. GUIDELINES FOR DESIGNERS

Procedures exist for the selection of appropriate fixing systems given different materials, structural requirements, and so on. One set of criteria was produced for the Royal Institute of British Architects, and has been summarised in Table 2[14].

Table 2
Summary of Primary Selection Procedure

Criterion	Subsidiary Factors
Structural	Loadings, vibration, vandalism, material characteristics, ductility, ranges.
Movement	Required movement, tolerances, rigidity.
Installation	Effects on rest of building, finishes, inhabitants, performance, removability.
Durability	Treatments, longevity of material, cost.
Adjustability	Design life, reversible, necessity for periodic adjustment, temporary fixings.
Appearance	Visibility, compatibility with other fixings and finishes, cost.
Accessibility	Neighbouring components, location, insulation, condensation, finishes.
Responsibility	Supply, delivery, installation, checking of integrity.
Programme	Schedule, cost, performance, information.
Other	Protection from weather, interaction with other building components.

Most selection procedures of this type, however, assume existing fixing systems and do not assume the use of any kind of automation, be it factory based or automation on site. But experience in other sectors of industry suggests that the principles of "Design for Automation" will have considerable impact on the six stages of joining which were discussed in Section 3. The criteria which derive from a consideration of "Design for Automation" have been summarised in Table 3 and should be used in conjunction with the sections dealing with site installation and inspection in Table 2. Not all of the principles apply at every stage of the fixing process, but some dominate at different times.

The need to reduce the number of components and fixings is important in the earlier stages, whereas the need to simplify or eliminate complex robot motions, particularly "peg in hole" insertions, is more critical in the middle stages. Quality control is vital in the preparation and post fixing stages but becomes less important once the fixing is actually underway. Other factors, such as the need for a modular design of joining component, can be assessed in a similar fashion.

Table 3
Considerations of Design for Automation

Stage	Subsidiary Factors
Preparation	Modular design, quality control.
Assembly	Combine functionality, modular design, sequential operations, simplify motions, special feeders, reduce ambiguity.
Mating	Combine functionality, simplify motions.
Initiation	Combine functionality, modular, design, reduce number of fasteners, sequential operations, reduce ambiguity.
Withdrawal	Simplify motions.
Post fixing	Quality control, inspection, testing.

5. CONCLUSION

This paper has discussed the principles of "Design for Automation" and has presented guidelines which will help designers understand the difficulties associated with using automatic joining methods in cladding applications. The principles are based on research into joining methods which has sought to apply the experience gained by manufacturing industry to construction problems.

Many of the fixing methods used extensively in other industries are not widely used for construction purposes partly because of conservatism in construction sector with regard to the scalability and durability of new materials and methods. Previous experiments with industrialised building systems in the 1960's were certainly unsatisfactory in this respect. Considerable standardisation of fixing methods has been applied in manufacturing industry, which can enjoy the benefit of higher levels of repetition than are usually to be found on building sites. Therefore, it can be seen that considerable changes to current working practice will be needed to utilise site automation and factory based production technology in a general construction setting.

One of the wider aims of the research programme is to continue to develop and refine methods of comparing joining technologies from different sectors of industry. Preliminary results suggest that many of the joining techniques which are widespread in construction are unsuitable for automation when compared with those which are used in other sectors of industry, for example adhesives and push-fit connectors

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