PARTS-SET: COMPONENTS OF MODULAR BUILDING SYSTEMS

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ABSTRACT

It is possible to devise a components-based approach to the design and construction of industrial and commercial buildings without compromising architectural quality. Modular building systems, based on the components of the parts-set proposed in this paper, could provide an answer for building owners and users requiring flexible, highly-serviced space. This approach, whilst clearly not new, does however offer a benefit today which was previously absent, in that the concept of designing buildings with automation in mind is now widely held to be the key to facilitating the application of construction automation systems and robotic tools. Modular building systems could help accelerate this application. The paper argues that modular building systems do have a useful role to play and should not be passed over simply because they have ceased to be fashionable.

1. Introduction

The main thrust of this paper is that building construction should be seen as an integrated process consisting of complementary sub-systems, none of which can be sensibly automated in isolation [1]. The use of a parts-set [2] provides the common linkage between the automation of both the design process and on-site construction utilising a family of robotic tools. In order to gain the full benefit from the approach it is, of course, vital to develop and implement the whole family of robotic tools, not just one or two of them. Once a kit of parts has been established, it becomes possible to embody the components within a computer-aided building design package and to use them to construct real buildings. The use of the parts-set also facilitates the link between the design process and the off-site manufacture and prefabrication of components, since the application of flexible manufacturing systems, FMS, becomes more realistic when a limited range of components is involved. In short, system building should be viewed as a means of integrating the whole process of building design, off-site manufacture and on-site construction. It does not need to impose uniformity on finished products unless, of course, there is a deliberate intention to do so.

Manufacturers of components already modularise their products for economy. For example, cladding panels are available in well-defined ranges of sizes and thicknesses, and steel is available only in standard sections. The main point of these two examples, of the many that exist, is simple: it does not make financial sense to produce a one-off for every project. Manufacturers find ways of standardising components and extending production runs in order to remain competitive. Despite this, few people would seriously suggest that traditional forms of construction are restricted because of the narrow range of section sizes and properties that are currently available.

2. Components in the Parts-Set

It is not possible in such a short paper to describe the components of the parts-set in any great detail; the purpose here is to provide an overview. More detailed specifications are given elsewhere [2] [3]. To aid categorisation, a typical building has been split into three areas of interest:

1. Structural Frame.
2. Internal Environment and Services.
3. Cladding and External Envelope.

Each of these areas is examined in subsequent sections. For each, the principal components are identified and the likely modes of jointing and fixing are considered.

2.1 Structural Frame

Following in the traditions of Le Corbusier's Dom-Ino House [4], the various sub-systems of frame, services, floor and wall units, environment and cladding are decoupled as far as possible. This separation of functionality allows designs to be developed using components sourced from different manufacturers, but without compromising the standardisation within the parts-set. What is required is that each sub-system of the building conforms to pre-defined standards and protocols which ensure ease of fixing and placing by automated methods. While there is an element of customisation between designs, the use of a set of standard components means that the finished frame design can cope with a wider variety of floor, services and cladding layouts than would otherwise be possible using traditional building technology. Moreover, the principle of decoupling functionality between systems will allow individual items within the parts-set to be upgraded with a minimum of change in other components.

As a starting point, the structural frame elements of the extended CLASP Mk 6 system of building components [5] [6] were studied. Within this structural frame are three distinct areas of interest which have been examined in more detail:

1. Foundations.
2. Main Frame.
3. Structural Floors.

Foundations are generally pad and strip footings of lightweight, aerated and autoclaved, precast concrete. Where necessary, it is assumed that foundation units can be joined by bolting or grouting and can be prestressed by a system of post-tensioning. Also, provision for pile caps and vibro-flotation heads is assumed, thereby enabling buildings to be erected on weaker bearing material. Commercial precast concrete foundation systems have been developed in the UK, based on experiences elsewhere, for instance in Scandinavia [7]. Other suitable materials for the foundations include timber, composites and certain plastics predicted to become available in the next ten years [8]; but of these, only timber is likely to be sufficiently cost-effective to compete with precast concrete.

The main frame is assumed to be a set of discrete components that can be made from any material, although a useful set would include steel, reinforced concrete, timber and certain plastics. The main members are columns, beams, braces and roof elements. It is intended that all current shapes of structural steel are used in the parts-set, that is I-beams, H-beams, angles, tees and hollow sections. Jointing and fixing methods are assumed to be centred around mechanical fasteners such as bolts and pop-rivets, but glues, welds and snap-fittings have been considered. Staircases are taken to be a part of the main frame and are intended to be fabricated from pressed metal, laminated timber or precast concrete. Timber roof trusses are already being produced by partial FMS technology in the UK.

Structural floors are composed of composite block and overlay, spanning between secondary members of the main frame. Proprietary systems exist in the UK, based on precast concrete or timber, and are designed according to global loadings and spans. Designing and specifying a structural floor in this way is common but by no means standard practice. The limiting factor with these systems is the deflection of the floor under load. To this end, it is proposed to develop a two-way spanning system which is either post-tensioned or otherwise mechanically fixed. Covering layers of a sheeting material such as a low-grade plywood can be used to give a continuous finish, once the holes between blocks have been filled with grout or mastic.

For each area of the structural frame, typical member sizes and weights have been estimated based on the functionality of the component concerned. By using these components, the bare skeleton of the building can be constructed, ready for the internal environment and the external envelope.

2.2 Internal Environment and Services

The second area of interest deals with internal layouts, services and environmental control systems. This area is especially interesting because of the way in which local services are pre-fitted into factory-built components, rather than being fixed on site around a set floor plan. While each of the service systems are designed separately as continuous circuits, they are set in voids within components and then connected together at junctions of discrete floor, wall and ceiling units. In this way, the floors, ceilings and partitions do not merely divide space and provide finishes, but also carry the services and sensors needed for environmental control. This approach does not rule out the possibility of having custom-designed services for a building, and goes much further towards allowing the building to be reconfigured with a minimum of effort. Such designed-in flexibility will be expensive in the short-term, but will more than pay for itself over the whole life of the building as subsequent refits arise [9].

In the parts-set, there is a clear distinction between the components which are required to divide space and the services which they carry in order to monitor and maintain a high quality, internal environment. These two elements are then further sub-divided into floor, ceiling and wall components, and other components for heating, ventilation and air-conditioning (HVAC), electrical and communications systems (ECS). Lastly, there is the issue of placing services where they are accessible, for example into floors, in preference to ceilings.

Floor units are similar in concept to staging sections used in theatres to build up different shaped stages. They are envisaged as prefabricated cages, covered by a suitable flooring material, containing all of the services that are required for an area and needing only simple on-site operations to connect them together. Provision will be included for moving the cages across the structural floor and for levelling them once they have been placed. Rigid connections between the cages might be effected simply and effectively using snap-fit connectors turned by cams within hollow frame members. The finishes could be applied in the factory or added later. A mobile robot has been postulated to aid in the process of moving the floor units [10].

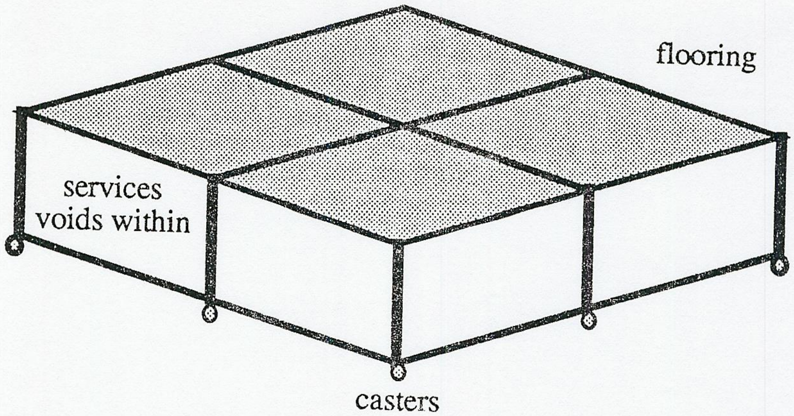

Figure 1: Basic Concept of Floor Units
Containing Built-In Services

Partitions are intended to be fully demountable and made from profiled sections of steel or similar material. By arranging sections in particular ways, it is possible to build service voids into walls which are separate but which could be connected if required. As with the floor units, the partitions could be supplied pre-finished or in a form suitable for later on-site work. This latter approach would limit the flexibility of the system as a whole, since the risk of damaging the finishes would be a disincentive to reconfiguring the layouts. Care will have to be exercised to ensure that the services in the floors and ceilings can be reliably connected to those in the partitions. To this end, it is intended to make the interfaces between partition and floor units, and partition and ceiling units the same as between individual floor and ceiling cages. The robots necessary to place the panels have been specified elsewhere [10] and are akin to those developed in Japan for placing partitions and erecting ceiling elements [11].

The ceiling system is a lighter version of the floor system and is suspended from hangers set into the structural floor. As with the floor cages, any services can be laid out in the cages prior to their leaving the factory. Similar comments apply to the on-site fixing, levelling and manipulation requirements of these components - suitable designs for robots exist in Japan [11].

The services which go into the components can be characterised as either ECS or HVAC. The former requires runs of cables with suitable connectors at each end, the other needs reliable ways of forming air- and water-tight voids both within the components and at their many junctions. The electrical and communication needs of modern, high-tech buildings means that dense servicing is inevitable in keeping pace with the demands for power, networks and flexibility. By placing a minimum level of cabling within every floor cage and partition panel, a local connectivity can be guaranteed for every user. Inevitably, this will mean high initial redundancy in cables, but improved distribution of computing power and information should more than compensate. Using separate voids within the components for different services will mean that upgrading individual systems becomes easier. Conceptual work on fixings, fixtures and connectors has been carried out with promising results [2].

HVAC services need plant and ducts to circulate air and fluids. Local, rather than global, services are envisaged which will allow users to create their own microclimates with respect to heat, humidity, ventilation and light. This means that many small pieces of plant will be needed instead of one large set located on the roof, but there will still need to be centralised, facilities management and control to ensure that the building is not being run inefficiently. The design of ducting involves compromise: ducts must fit within components, yet should not be inefficient because of their size or frequent changes of direction. Additionally, there has to be some means of access to the joints between the ducts in order to make connections, to verify them later, and to decommission them when the floor layout changes.

2.3 Cladding and External Envelope

The third area of interest concerns the enclosure of the building. Apart from the obvious need for external enclosure, other objectives include making cladding energy-efficient through the use of transparent insulation and reactive glazing, and accommodating the potential for re-cladding or over-cladding. In a more detailed study of the cladding process [3], it was found that a cladding system could be conveniently divided into three areas:

1. Cladding Panels.
2. Joints Between Panels.
3. Fixing Systems.

For each of these, current building practice was examined and any ramifications for an automated system were noted. The end result of the study was a detailed description of panel sizes and weights; joint profiles and jointing techniques; fixing methods and components required; automation tools and aids necessary to carry out operations; and an erection sequence for a robotic cladding system. Similar studies will be necessary as other areas of the parts-set are developed in greater detail.

Cladding panels can be of any material as long they obey a set of rules which facilitates their manipulation by robot. In this way, the designer is given the freedom to clad the building in almost any style using large-panel methods. Provision has been made to allow the building to be clad in more traditional materials such as brick or render. Panels can be of many shapes and sizes, constrained only by the total weight and certain key dimensions. In other words, a panel must be of such a weight and size that it can be lifted safely by the robot.

Joints between the panels are based on adaptations of current building practice and are applied from within the building rather than from the outside. This is made possible by installing a joint treatment on the panels in the factory and then finishing the joint after it has been placed.

In addition to the material considerations of the cladding panels is the need for a set of purpose-designed power tools to aid in the jointing process. Many of these comments also apply to the fixing process, in that parts can be fixed to the panels and to the structural members off-site, thereby speeding up the on-site processes. At the same time, the use of power tools to aid in the installation of fixings would mean a reduction in the time that it takes to place a panel and thus a reduction in the length of time that the robot is likely to be idle. The general arrangement and relationship of cladding panels within the structural frame is shown in Figure 2.

The parts-set approach offers more flexibility than past building systems, because of the close integration of computer technology, manufacturing processes and construction methods, and the way in which functionality is strictly specified in each system. Much of this is derived from the way that each component in the parts-set will have been designed according to strict criteria [2], thereby ensuring compliance with the philosophy of the parts-set approach.

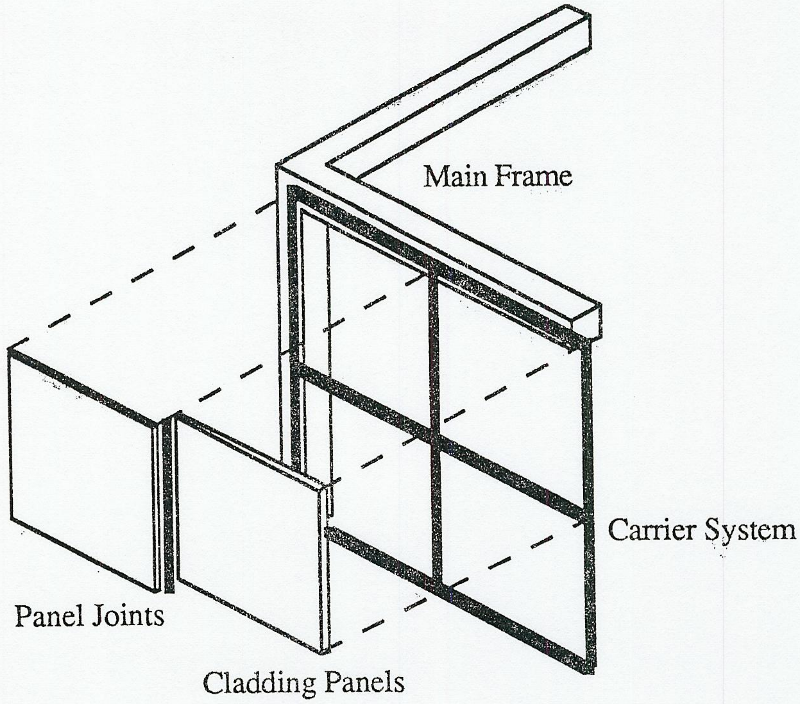

Figure 2: Cladding Arrangement and Relationship to Structural Frame

3. Conclusions

The research described in this paper emphasises the need to consider automating construction as a whole and to avoid a piece-meal approach. A set of parts has been proposed along the lines of the CLASP Mk 6 building system, although incorporating much that is new. This is especially true of the services and associated technology of production, enabling parts to be manipulated on-site and prefabricated off-site using robots. Research is being directed towards refining these parts and investigating their suitability for object-oriented building design. The project of which this research forms a part proposes to specify only the cladding components of the parts-set in any detail and to represent them in a scaled-down computer program.

4. Acknowledgement

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