DEVELOPMENT OF BUILDING MODULE TECHNOLOGY

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SYNTHESIS REPORT

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Dragados y Construcciones SA

R B Farquhar Ltd

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MODULES IN

CONSTRUCTION

Project funded by the European Community under the BRITE EURAM programme

SYNTHESIS REPORT

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THE DEVELOPMENT OF BUILDING MODULE TECHNOLOGY

BRITE EURAM PROJECT NO BE-4417

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ABSTRACT

A consortium of eight project Partners from across Europe funded by the European Commission under the Brite Euram programme have undertaken research into building module technology.

Detailed investigation with stage reporting was undertaken to establish initially the existing status of the European module market, then to review material technology, loading analysis and transportation, which resulted in the development of new Global Specifications.

The primary objectives for the project required the establishment of a structured approach to the design, production methodology, installation and use of building modules, that is at present lacking with the European Construction Industry. Also to seek a basis for creating improvements in understanding the cost and production implications of building modules.

This study culminated in the manufacture of two different prototype modules, the development of a patented design for connecting structural connectors which were analysed and tested using "state of the art" computer modelling techniques and a software programme to assist the module manufacturing industry.

INTRODUCTION

Developments in improving the technology and use of building modules within the European construction industry have tended to result from the enterprise shown by individual manufacturers in meeting their own client's needs.

A survey of major European module manufacturers was undertaken to determine the current "state of the art" among major module producers. This revealed a wide range of products designed to meet different market needs. While some manufacturers have tailored their modules for a specific end use (such as bathroom modules), others have developed a range which can be refined and adapted to suit almost any purpose.

The majority of the module market comprises small organisations producing a wide range of products from modular toilets (commonly known as pods), through site accommodation units to low rise volumetric units, or producing system buildings, not truly modular.

Module dimensions have evolved independently within the relevant European transport limitations to produce a rectangular box design averaging 13m x 3m. The common aim has been to produce free-standing, fully fitted units requiring only connection to each other and site services upon delivery. Within this objective, manufacturers have developed their own solutions to the common problem using a variety of materials, structural designs and connection systems. While some modules have been designed for up to two storeys, as is commonly required in long term temporary situations, more enhanced systems also exist for up to four storeys, but this is rare. These serve as permanent structures which may even be given the appearance of totally traditional construction.

One and two storey systems have been developed in lightweight precast concrete and timber and in both lightweight steel and aluminium. Some designs feature a structural skeleton onto which the body of the module is added while other designs utilise all panels as structural components. A review of three storey systems shows lightweight steel sections prevailing up to a maximum of six storeys achieved by a modular system developed by a Belgian company.

Standards for sound, heat and fire insulation vary somewhat between modules but often the manufacturer can enhance these performances to suit the Clients needs. Sound insulation providing 40 dBA noise reduction is already within the reach of most manufacturers and would seem a sensible benchmark around which to base a new design. Similarly, thermal insolation providing 'U' values of $0.45 W/m^2K$ and fire containment of one hour would appear readily attainable by current manufacturers and should serve as a reasonable datum on which to improve.

External appearance is one design area where manufacturers have taken individual leads. While most have applied the latest materials technology to give a resounding hi-tech image, some have also considered the demand for a fast track building system which can maintain traditional styling where necessary to convey a client's corporate image.

Modules have been designed in European countries to meet their relevant national codes. Where these codes are not sufficient (e.g. Belgium) then those codes which are conventionally used as construction guidelines have been adopted (i.e. French). There are currently some 150 European Standards (EN's) in use in the Community, some of which will be applicable to modular design. There was particular reluctance from some countries to provide data for the research. This was particularly noticeable in France.

In essence, the European construction industry has lacked a rational and structured approach to the design, production and use of building modules, as well as the establishment of a unified acceptable basis for improving the cost and production implications of building modules across all national boundaries.

Since the commencement of the project at the end of 1991 the declared objectives of the Partners has been to improve the cost effectiveness of the use of building modules across the full range of building types with the resultant benefits from the cost savings, quality and precision of construction which modules can offer. Further, this would be achieved by adopting production and manufacturing techniques from other industries in order to make competitive improvements in the choice of materials and the manufacturing process.

The results of the study provides guidance to European module producers through the adoption of a co-ordinated approach to the design and manufacture of modules and in the development of global standards.

TECHNICAL DESCRIPTION

The means used to achieve the objectives was to dividethe project into the following separate and distinct technical areas;

Definition Stage

The detailed survey of module producers and their products, was undertaken to establish the current state of the market. The resulting report on the European construction industry requirements for volumetric modules, based on this survey, led to the production of global and particular specifications, which took into account national codes arid standards and which provided a basis for technical development within the project.

The project Partners made a joint decision to focus the main area of work in the study, on the requirements for a four star hotel bedroom/bathroom volumetric module capable of being stacked to six-storeys and to be substantially fabricated within a factory. The reason for this facility was that it contained all the elements being studied and the results could therefore be applied to a broader range of applications.

Module Structure Technology

Specifications for the handling of modules during manufacture, transportation and site installation were prepared, together with a report on the detailed technical specification for a module box structure. Information was collated on the loading conditions for modules and redistribution of loads through the completed structure.

Particular considerations were given to the development of simplified methods of making structural connections between modules. An assessment of technologies and materials from other industries was undertaken and structural designs prepared based on the detailed specifications.

Materials Technology

A comparative review of the factors and range of materials or components likely to be used in the manufacture of prefabricated building modules was undertaken. Particular emphasis was placed on the development of fully finished sub-modular elements for the walls, floor and ceiling, to complement the structure of the modules.

Services Technology

An important feature developed for this project has been the use of “motherboards” for the accurate and fast assembly of plumbing. The method of designing and installing the services in a modular building and exploiting such a feature, creates not only a reduction in cost, with a saving in material costs due to the tight control of inventory and reduction in waste, but also the ease of servicing is unique.

A full review of all services and alternative materials that might be installed in a module, together with consideration given to grouping of services in sub-modules was carried out, together with a study of methods of making simplified services connections between modules.

Production Technology

The building module produced by R B Farquhar was used by the project Partners for assessing the effects of alternative production methods, with the aim of reducing labour costs, whilst satisfying the architectural, structural and service requirements for the module.

The frame is made up of hollow section steel beams and columns connected by means of nodes, held in place initially by adhesive applied prior to pressing into the hollow sections, and which when clamped the nodes are drilled and pinned. Panels forming the walls, roof and floor are made up of galvanised steel sheet, fixed with adhesive either side of an insolation core.

Software Development

Initial studies to locate areas which would benefit from computer support resulted in the concept of building a computer integrated manufacturing model for the modular construction industry leading to the testing of this concept by building a maquette, referred to as CIMIC. The basic architecture of the CIMIC provides the following four basic functions:

a) Integrating the CAD data from design.
b) Order entry.
c) Selecting the correct process plan.
d) Scheduling the assembly work.

Prototypes

Two prototype modules were developed, one to Southern European Standards by Dragados y Construcciones (DYC), and the other to meet Northern European requirements by R B Farquhar (RBF).

The DYC prototype was a heavier construction than the RBF module and consisted of an external prefabricated concrete window wall, a concrete floor and strong steel frame. The design of the module required horizontal forces to be resisted by stiff structural elements incorporated within the modular building.

In both prototypes, interconnection of modules is achieved by means of patented iron or steel node connectors.

Both the RBF and DYC modules are capable of being stacked to 6-storeys, and are appropriate for use in a range of markets and use applications. Each of the modular forms utilise specially developed structural and services connectors. The factory assembled RBF module was carried out to a higher degree of accuracy than originally expected of a prototype.

The project Partners believe that with a well structured production methodology, incorporating detailed planning of fittings and furniture and the use of standard production equipment, the application of good quality assurance procedures and stringent control of subcontractors, it should be possible to achieve a completion rate of the RBF prototype of seven modules a day.

Based on a semi automated production approaches, minimum factory turnover of 1650 modules per annum, the saving on "traditional" approaches can be as much as 50% on this lightweight RBF volumetric monocoque module over their present approaches of the prototype.

Comparisons made with a building of traditional construction showed that savings in excess of 10% could be made for a 6-storey 130 bedroom hotel.

RESULTS

The detailed results of this project maybe considered to fall within the following main areas:

- Although the project Partners had individual detailed experience, no formalised statement existed setting out the global performance requirements of various components within a module. Appropriate production methodologies were established and an expert system tool covering module design and on-site installation was organised.

- Detailed wurk was undertaken to establish modules which were robust, but lightweight, could be constructed within tight tolerances and maximised the efficient use of factory production techniques. Designs were evaluated in terms of their optimum production requirements with the final designs and sub-modular elements of the prototypes tested against the performance requirements of the detailed specifications.

- Specifications were prepared, adhering to the global performance parameters of the modules, which set out the constraints (loadings, tolerances, environmental effects, etc.) that the different components of the module finishes were required to meet and thus establishing, by means of a comparative review, the range of building materials which provided the optimum solution to completing the finish and interior of a module.

- A fundamental criteria of the project was the establishment of the range of appropriate services functions, in terms of power, lighting, water, waste, heating and ventilation together with a critical assessment of the means in which a very high level of completion and commissioning of services could be carried out in the factory with the consequent minimizing of site operations.

- Exploitation of the design production methodology has been an integral part of the module design and has had a major influence on the final design of the module floor, wall and roof panels, together with the frame. The development of service fitting and assembly within the module prototypes is unique, as is the method of frame member connection by the use of nodes.

- An innovative aspect of the project was the Computer Integrated Manufacturing for Modules In Construction (CIMIC) software, which enables the module manufacturers to manage all aspects of their production within one software package. CIMIC covers order entry, product definition, production site configuration, production planning and scheduling in one integrated package

- Development of inter-connection technologies for the purpose of identifying way in which modules can be efficiently used within buildings or as free-standing structures.

- As a result of construction of two different prototypes by DYC and RBF, as 2 storey elements of 6 storey buildings, and the testing of elements of each, sufficient means of judging the technical developments generated by the project including improvements in understanding the cost and production implications have been developed.

CONCLUSIONS

The Present Industry

Research into the modular market showed that the supply of modular units for developments ranging from single to three storey heights is adequately covered by the industry. Such modules are usually built in a timber framework, structural steelwork or a mixture of these materials or precast concrete. A few specialists in modular construction produce separate units which can be built to four storeys, typically using structural steelwork elements, however, there is the absence of a system covering the high rise market (including hotels and offices) having a factory produced “dry system” approach.

It was decided to focus this project on a four star hotel bedroom/bathroom volumetric module capable of being stacked to six storeys and substantially fabricated within a factory.

This approach was taken because it involved a range of approaches that would be common to other appropriate applications. The module structure and services were to be interconnected without the need to access the interior of finished modules, in order to limit or alleviate the need for external access during construction.

The Prototypes

Two different prototypes were developed.

Spanish regulations on hotel room sizes and transportation limitations determined the layout of the DYC module. It utilised more traditional materials than that produced by R B Farquhar, but assembled in a manner more appropriate to factory production. Lateral stability was achieved by providing stiff end towers and within the development period DYC made progress towards lighter modules. Innovative ideas introduced included “half modules” connected to form hi-modules and the development of the Colfix node.

Within the RBF design, the stacked modules had to be able to resist horizontal forces. Several innovative concepts were introduced:

- The composite panels as structurally resistant elements, the module box acting like the monocoque frame of a car.

- The cast iron node, which provides a quick and efficient **way** of assembling tubular elements.

- The use of adhesives in connections - this technique being well known in the aerospace and automobile manufacturing industries but, little used in construction.

- The Spirols act as "fail-safe" elements (a concept borrowed from the mechanical industry),

  Consideration was given to the use of alternative materials from those normally associated with the building industry, particularly pultruded fibre reinforced plastic (PFRP) and adhesives. Following a detailed study by, PFRP was discounted from being suitable material to be used in module construction. structural adhesives were adopted for use in the DYC Colfix node and the connector node developed by RBF and also in the formation of the composite wall and floor panels used in the RBF prototype.

Services **Technology**

The services solutions developed have allowed them to be integrated with the box module and the internal finishes, while complimenting the architectural detailing. At the same time they have satisfied the need for a high level of completion and commissioning within the factory, with a consequent reduction in "on-site" operations. Costs may also be reduced to below those of the traditional structure,

Production Technology

The production methodology used for this project has been developed from industrial applications and has been applied primarily to the lightweight volumetric Farquhar module. Design of the module's frame and panels was based on extensive use of jigs and fixtures to maintain dimensional integrity, allowing for very short assembly time cycles.

Considering that this was a prototype module built in an industry which is not used to industrial or production disciplines, the assembly of the module was completed well, with a higher degree of accuracy than was originally expected. Most of the problems that were encountered proved the need for a high degree of detailed planning and detailed design. The attitude of "making it fit when required" would not be acceptable in meeting the production requirements for this type of project. The design detail of the frame parts, and panels was extremely good. There has to be a much higher degree of detailed planning for the fittings and furniture. For instance, the detail of assembly and fitting of a light socket or the fitting of the case rack or wardrobe on to the wall is extremely important, as these features are only given a few minutes of production time, so they must fit the first time.

These lessons were apparent in the prototype and several unique features developed such as those below:

- Unique design of complete wall units with embedded wiring and support frames.

- The method of using motherboards in the bathroom

- The design of light fittings and sockets to suit production methods.

- The methods used from observing the module assembly in fitting nodes to columns and beams

- The method of hydraulic clamping and drilling to ensure the side frames are square.

- The methods of frame assembly and sequence of operations for panel and frame integration.

Further simplification of the design, especially in the detail of fittings has been considered in the production report. With the use of standard production equipment and the application of quality assurance methods and disciplined control of sub-contractors, it is possible to complete seven of these lightweight modules per day.

Software Development

The task goals were more fully detailed towards the needs of the modular industry. The development of a model for a software tool to assist the modular building industry in planning their production, giving insight into the effects of design changes and allowing the industry to define a modular building technology. This evolved towards assemble-to-order manufacturing systems (instead of the current design-to-order/make-to-order systems), whilst at the same time giving the Client the same freedom of choice.

A prototype of this model was developed and tested on site. It was necessary to perform the work on that task in parallel with the design for the module. This meant that the model (and the CIMIC prototype) was developed based on a generic description of the manufacturing system of modular building.

The test data used throughout the whole project was modelled and updated frequently against the R & D progress made on the modular designs during the project, One of the major advantages and also one of the major achievements ofthe project, is that through approaching design and production of modular buildings in a generic way first and then detailing it towards the prototype hotel designs at the end of the project, concepts such as ‘part template’ and ‘assembly method’ were born, allowing the industry to evolve closer towards an ‘assemble-to-order’ approach. Whereas previously, acceding to a Client’s wishes meant that new or amended designs and adjusting or even changing the production system. This will not now effect the production so often as it will have been modelled from the outset. Through the use of CIMIC, the estimating phase will be based on more accurate data or even on simulations.

The achievements of the CIMIC concept were:

- Integration of the different stages (estimating, designing, planning, scheduling).

- Assembly method using generic part templates mechanisms, assisting the evolution from ‘design-to-order’ or ‘make-to-order’ towards an ‘assemble-to-order’ production system.

- More accurate estimating phase (almost no estimating in future).

- Simulation possibilities on:-
    - the effect of accepting an order on the current workload
    - resource planning (machines and staff)

- Cost and performance armlysis:-
    - evaluation and analysis of production

Project Achievements

The results of this project have been to create a vision by which a new generation of prefabrication techniques will provide flexibility, ensure quality for less cost and increase speed of construction.

The principal achievements can be summarised as follows: -

- The development of simple structural configurations to six storeys in height with the structural use of panels as stackable modules with a rationalised and economic layout.
- The research into and the comparisons between two module systems developed by Farquhar and Dragados.
- Rationalised production methods including the development of semi-automated and automated assembly approaches.
- The pricing studies have demonstrated that cost reductions in factory engineered approaches can be realised.
- Software modelling with the emphasis on the production processes.
- Simplified site construction connectors with no site attendance.
- Large panel fabrication using vehicle influenced manufacturing techniques.
- Use of structural adhesives for somesecondary connections.
- The development and now patented design for ‘connection nodes’.
- Economic and rationalised co-ordinated solutions for the installation and connection of services.
- Life cycle analysis and future adaptability and maintenance approaches.
- **A** review of a possible new generation of building design concepts towards total modulation.

It is hoped that this report will contribute to the development of a module procurement culture within the European Construction Industry for building production to satisfy a range of building functions and technical solutions. Also to provide guidance to European Module Producers through the adoption of a co-ordinated approach to design, manufacture, energy efficiency, transportation, erection, maintenance and life cycle assessment in the development of new global standards.

ACKNOWLEDGEMENTS:

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Taywood Engineering Ltd - Project Coordinator

Dragados y Construcciones SA

R B Farquhar Ltd

Bennett Associates

Hawtal Whiting Styling International Ltd

Haden Young Ltd

A I Systems SA

MSM Institut de Genie Civil, University de Liege

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ANNEX

SCHEDULE OF PHOTOGRAPHS AND DIAGRAMS

R B Farquhar Prototype	External views
Dragados Prototype	External views
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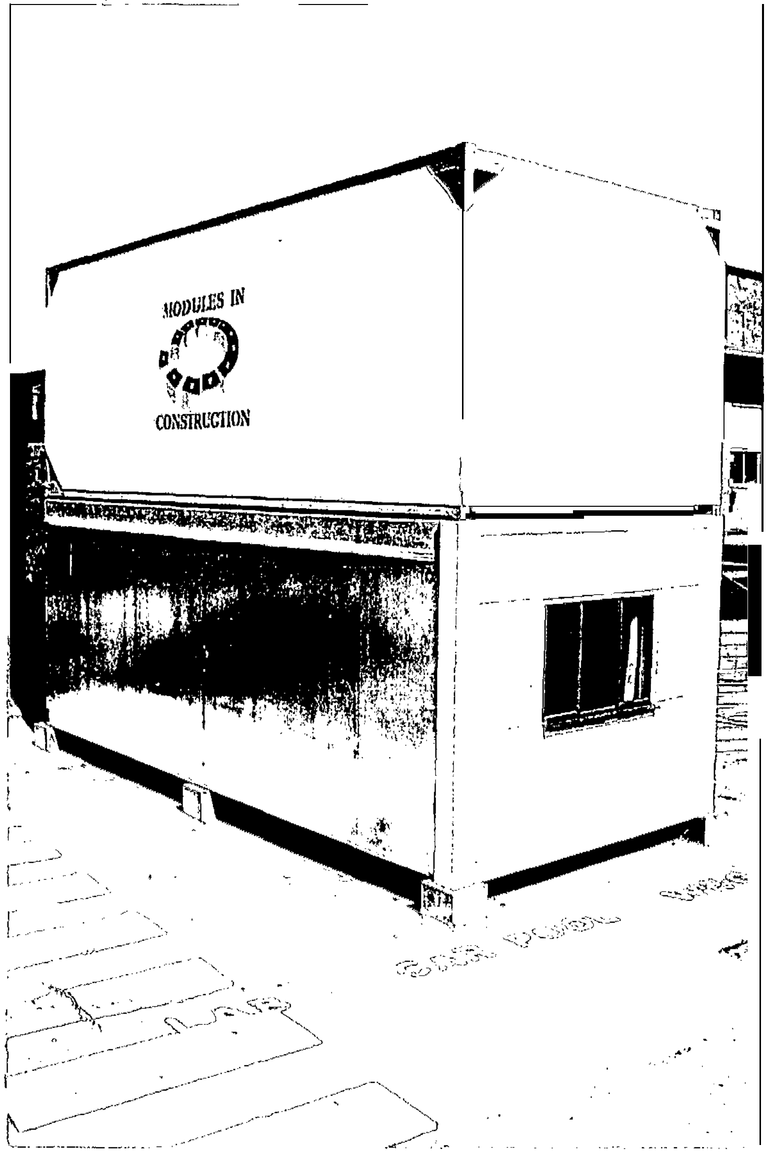
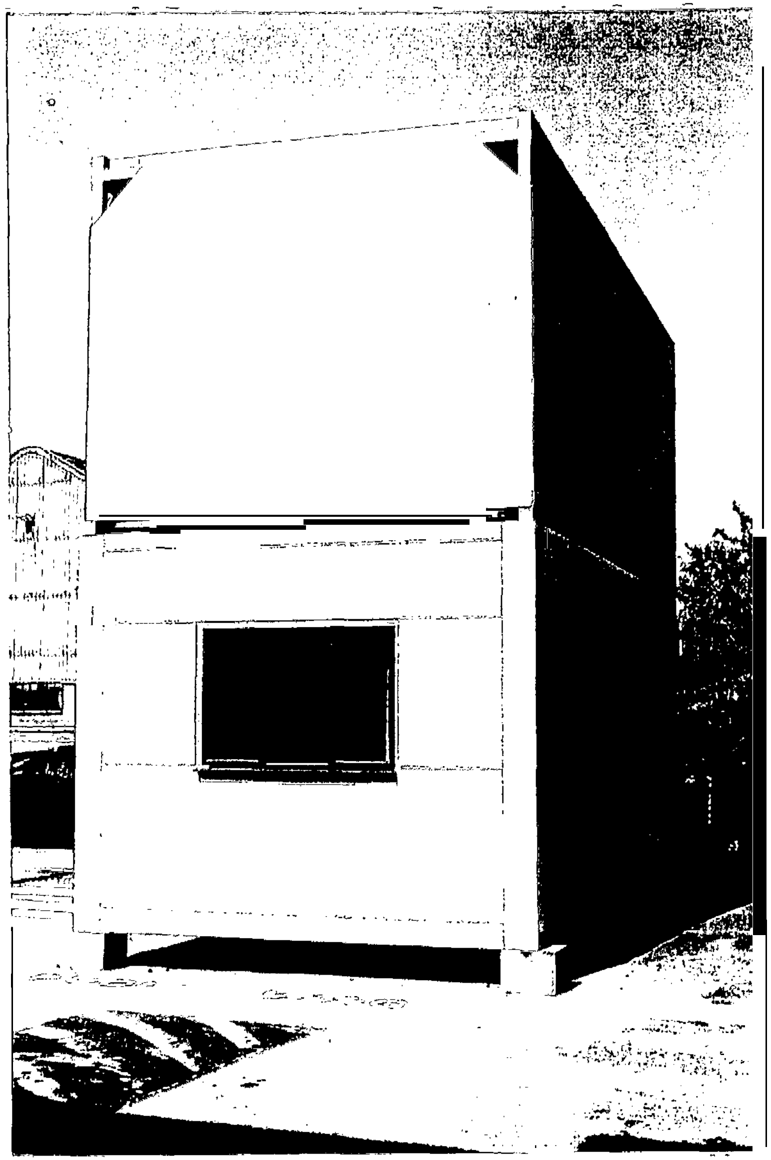
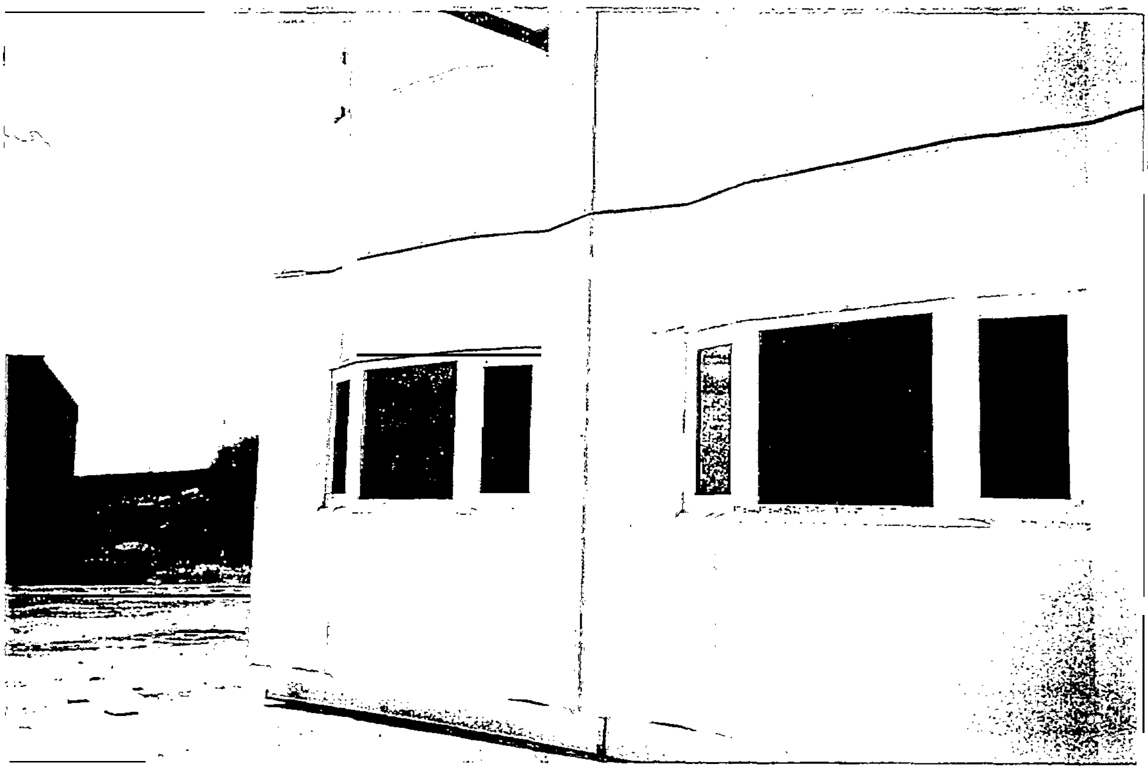
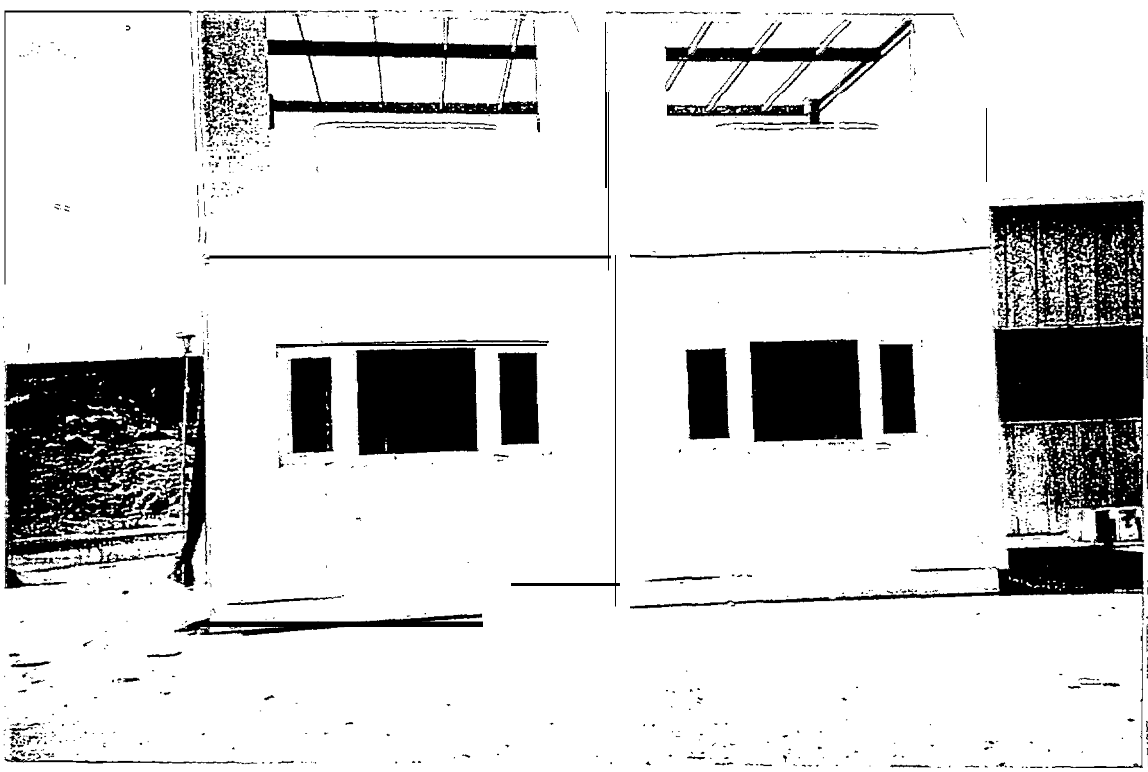


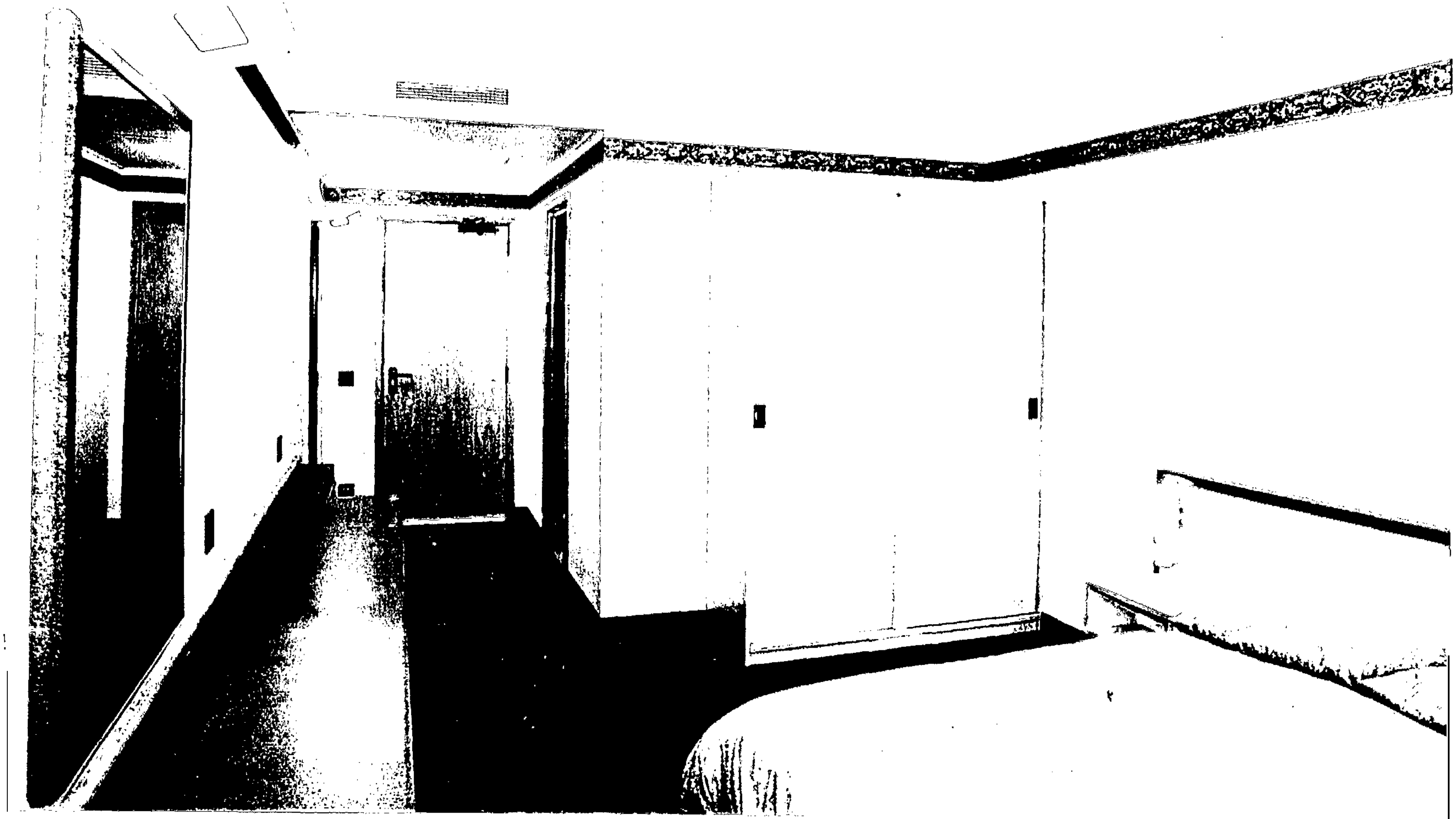


R.B. FARQUHAR PROTOTYPE - EXTERNAL VIEWS





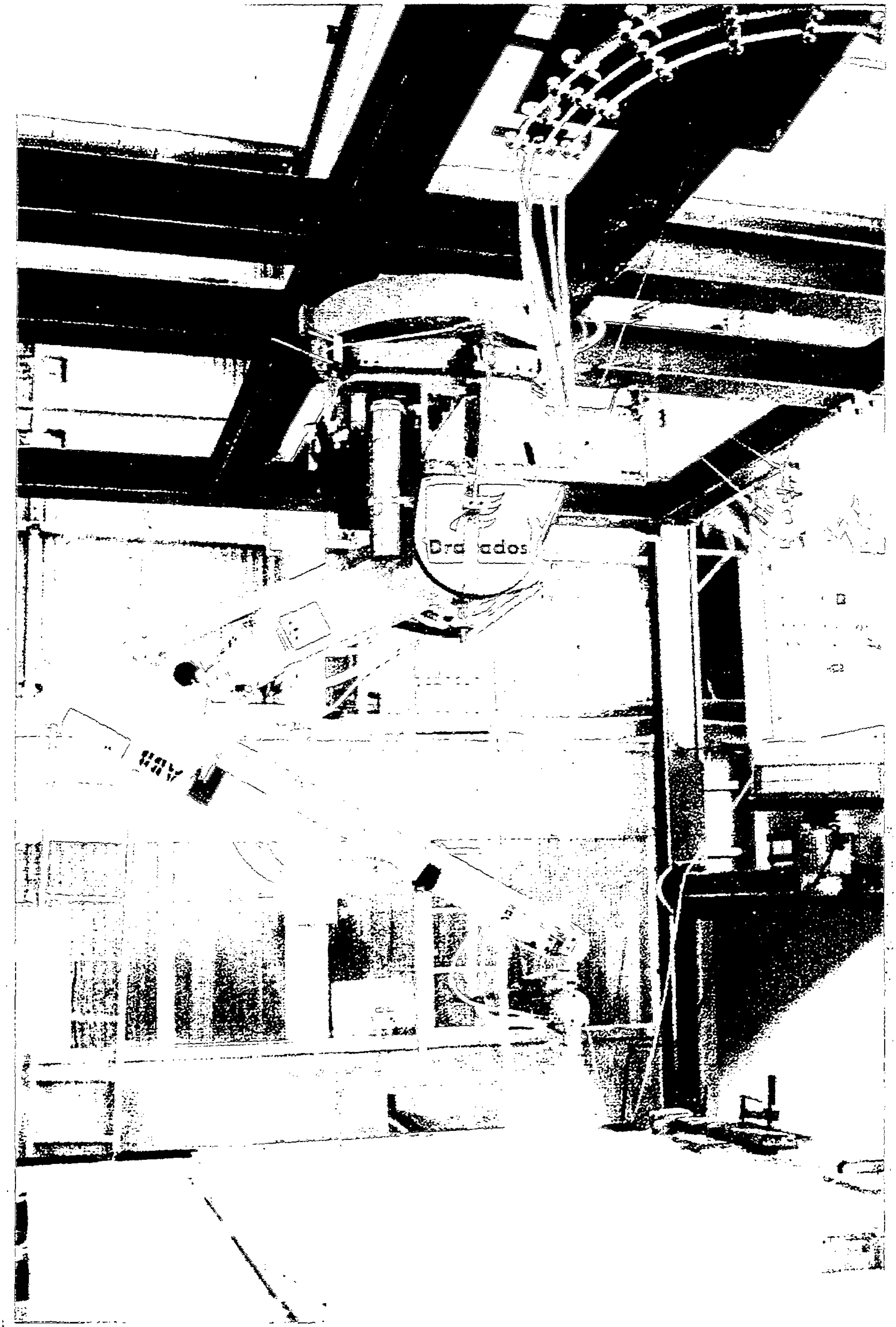
DRAGADOS PROTOTYPE - EXTERNAL VIEWS



R.B. FARQUHAR PROTOTYPE - INTERNAL VIEW

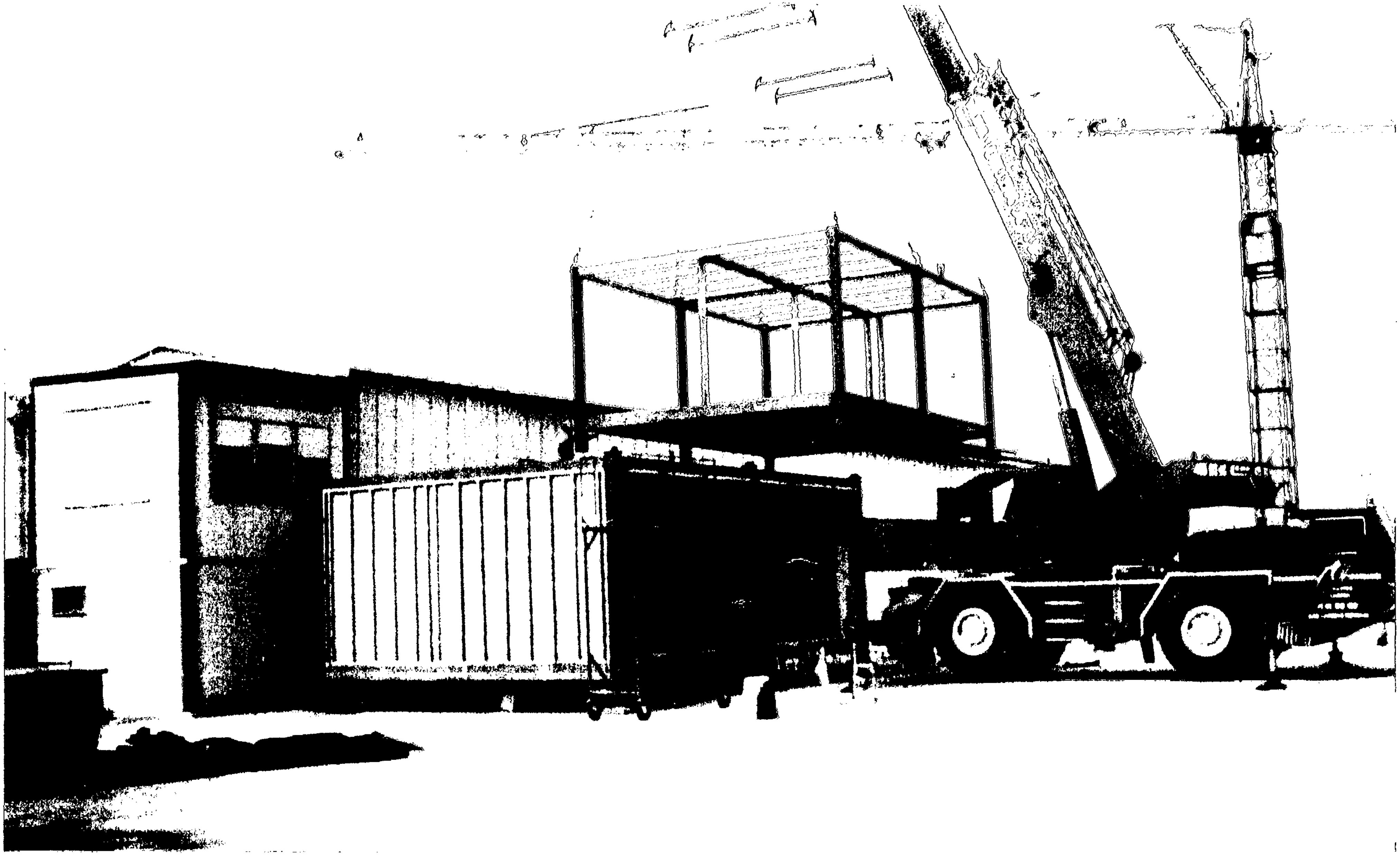
DRAGADOS PROTOTYPE - INTERNAL VIEW

R.B. FARQUHAR PROTOTYPE - FACTORY PRODUCTION

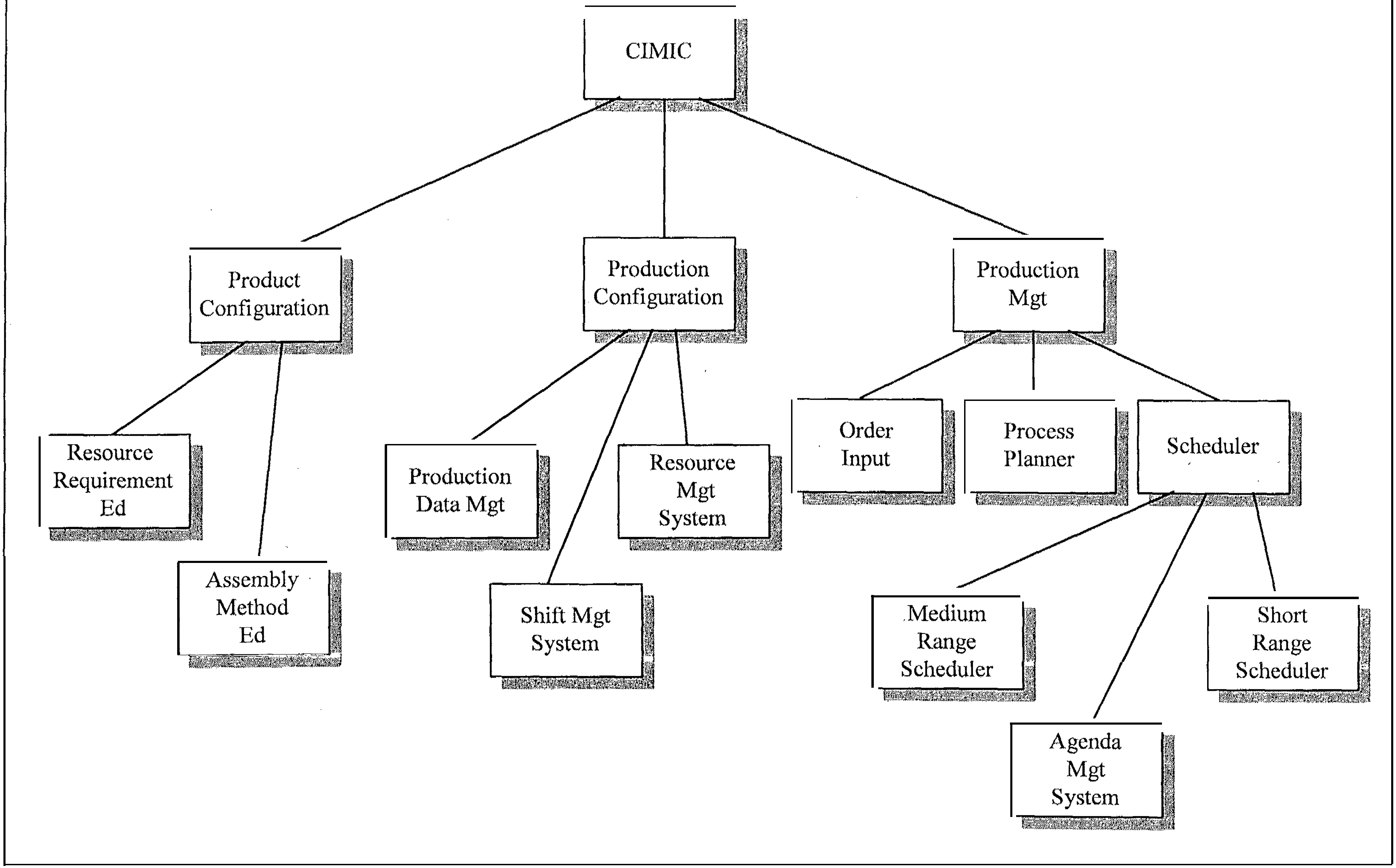


DRAGADOS PROTOTYPE - FACTORY PRODUCTION

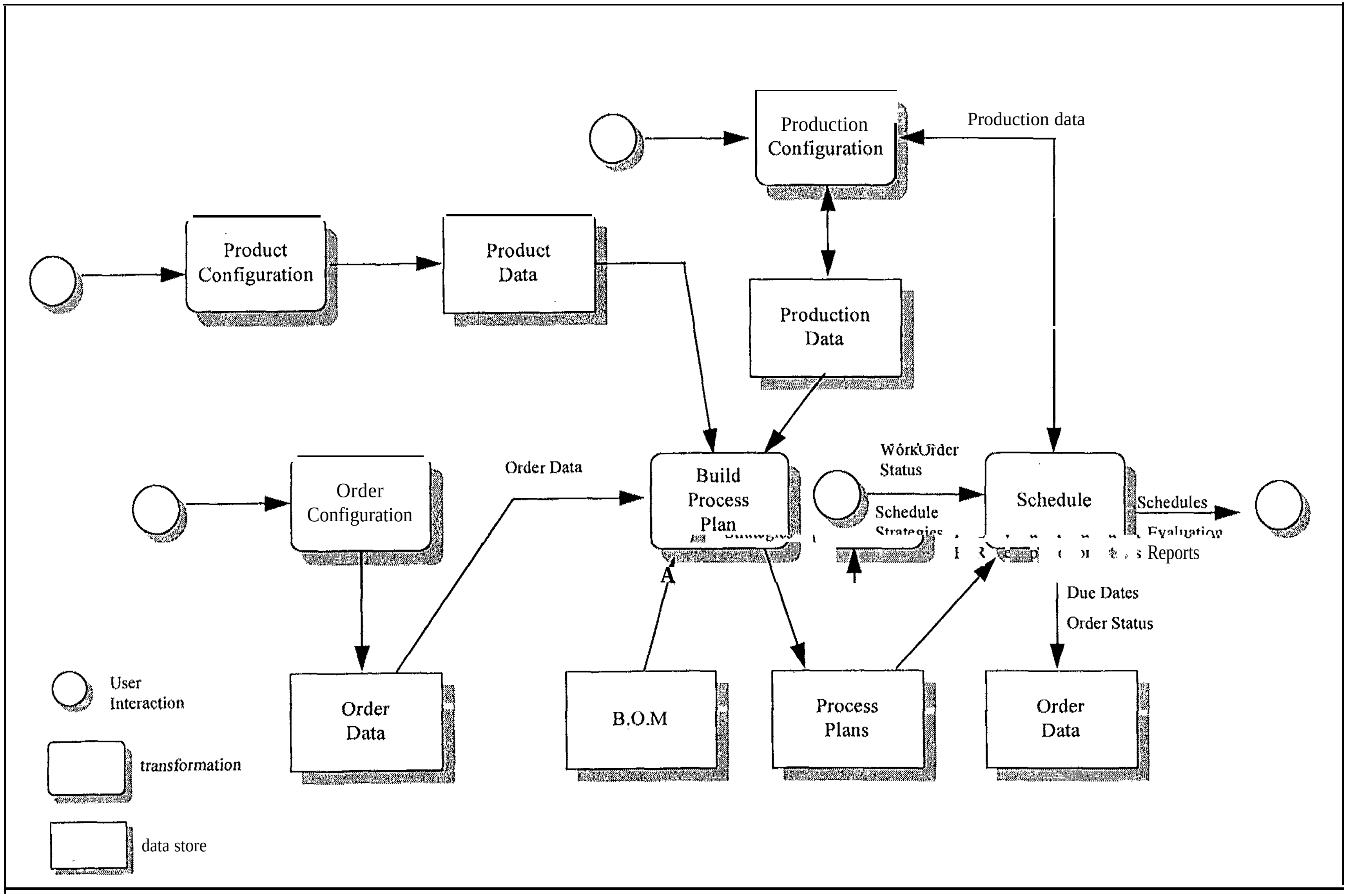
R.B. FARQUHAR PROTOTYPE - PLACING& STACKING



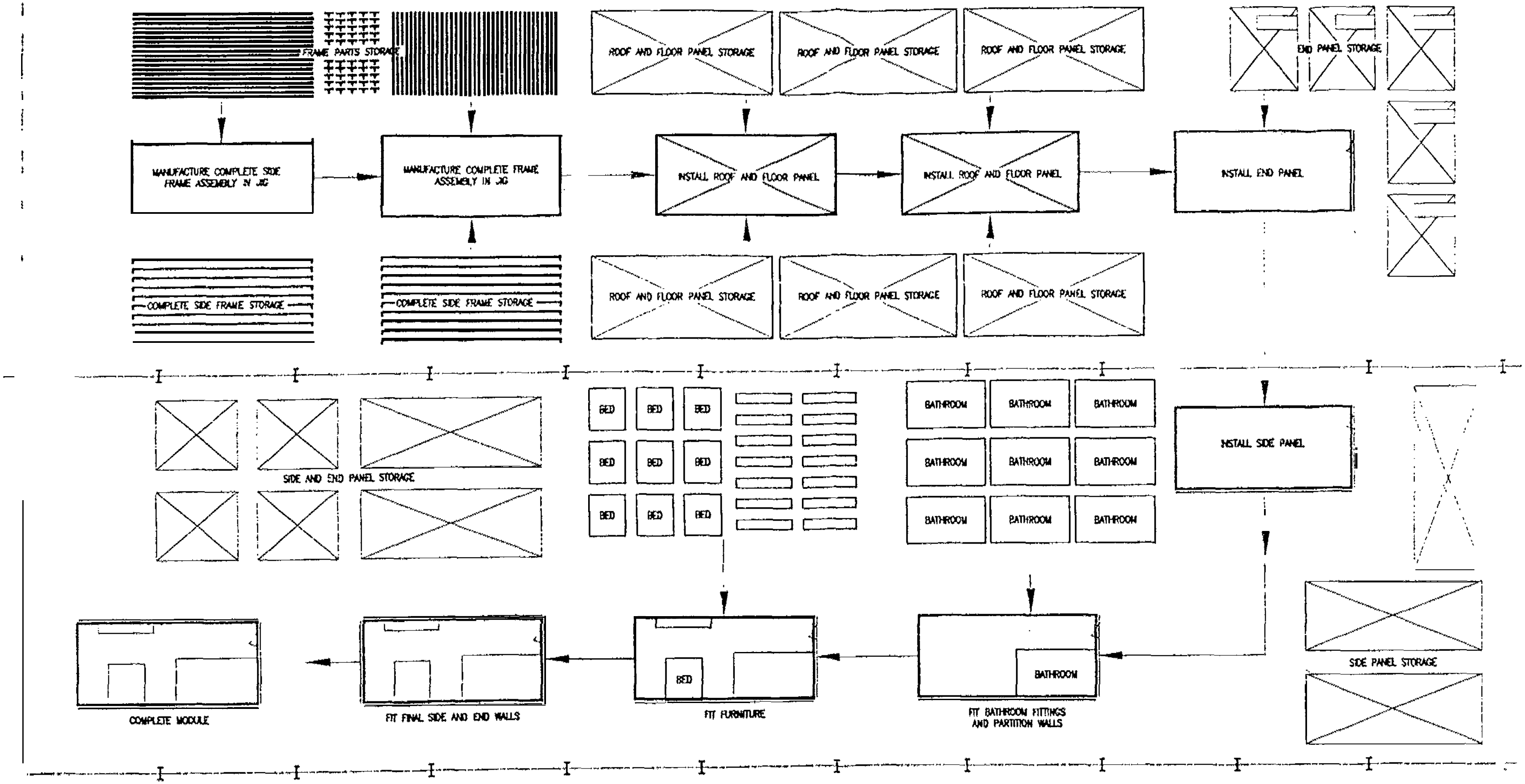
DR. GADOS PROTOTYPE - PLACING & STACKING

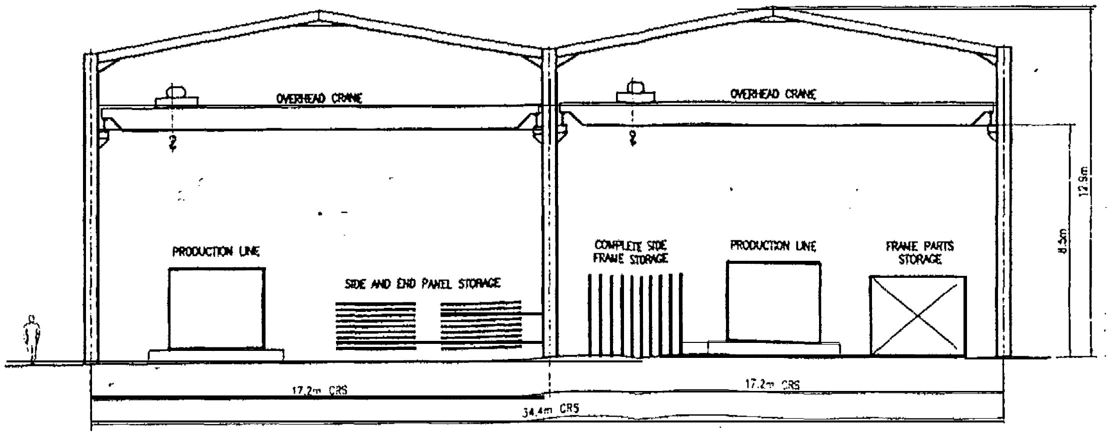


SOFTWARE DEVELOPMENT - CIMIC MAIN ARCHITECTURE



SOFTWARE DEVELOPMENT - CIMIC GENERAL DATA FLOW DIAGRAM





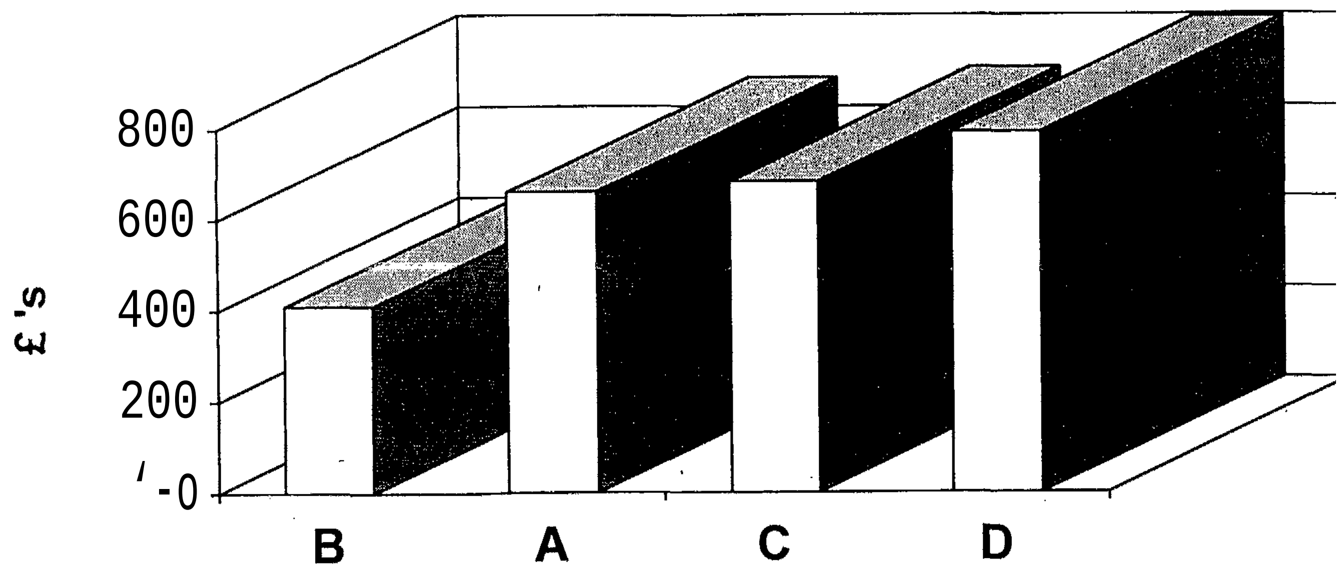
SECTION 'A'-'A'

BENNETT ASSOCIATES -
MODULE FACTORY PRODUCTION LAYOUT

MODULE TECHNOLOGY - COST COMPARISON
6 STOREY HOTEL -130 BEDROOMS
COST PER SQUARE METRE

A -Farquhar -Volumetric/Timber floor/Plasterboard
B -Farquhar -Volumetric/Stressed Skin/Metal Panel
C -Dragados -Volumetric/Concrete Floor/Steel Frame
D -Insitu -Traditional RC

Note: -Ground floor left in carcase



COST COMPARISONS