ADAPTABLE BUILDINGS: THREE NON-RESIDENTIAL CASE STUDIES

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Abstract
This paper describes the findings and lessons learnt from three adaptable non-residential buildings, as part of the Adaptable Futures research project, at Loughborough University, UK. In each case the business needs of adaptability, technical features of the buildings to enable these and changes achieved during the lifecycle are presented.
The buildings range from industrial to offices and two of them were designed to be adaptable from the start. The Igus Factory design approach –a totally flexible manufacturing plant in Germany- has facilitated the client's long-term plans increasing by four its floor area over a period of 17 years. The Civil & Building Engineering Department of Loughborough University in the UK was designed as a universal adaptable precast concrete building able to change to varying uses and be extended, however, when the expansion was needed -40 years later- a completely different solution was adopted. At last, the refurbishment of Silk Street offices -in central London, UK- is a good example of how to improve adaptability in an existing building to facilitate frequent changes. All those examples have been studied to identify strategies and design criteria to which adaptable buildings should respond.

Keywords: Adaptable non-residential buildings, business needs, frequent changes, multiple uses, building growth.

INTRODUCTION

These adaptable non-residential case studies are some of the examples studied by the Adaptable Futures team -a three year multi-disciplinary research funded by the EPRSC at Loughborough University, UK- to identify design criteria for a successful adaptable building, through literature review, buildings information and personal discussions with the people involved in the design, construction and maintenance. The key findings will be transferred and used within the UK construction sector. For each case study, the paper includes a description of the business and client needs of adaptability, a section on the technical features to enable these needs and the adaptations made to the building since constructed. The last chapter summarises the lessons learnt.

IGUS FACTORY, COLOGNE, GERMANY (1)

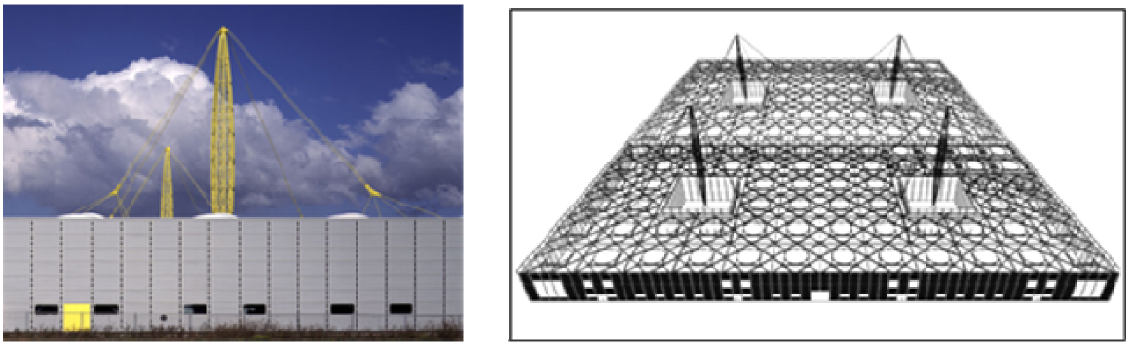

Figure 1: *Igus façade & full building made of 4 square blocks - 6 bays x 6 bays (Grimshaw)*

Description

Igus is a 'high-tech' plastic products manufacturer of energy supply systems, such as cables and all accessory components. Due to the company's tailor-made variant production, the factory produces thousand of new articles every year inspired by customer suggestions. This type of work leads to unpredictable and ever changing future which requires the production facilities to be re-configured within a short period of time in order to enable the company to deliver the new products effectively and satisfy their customers needs. The building's design gives the capacity to change the internal factory layouts rapidly and frequently, to care for the company's ever changing business needs, as well as for a rapid expansion.The adoption of such an approach has facilitated the client's long-term plans by easing the construction of each new phase. Inside the basic structure there is virtually nothing that cannot be moved or altered. In N.Grimshaw's words, the building is 'an up-to-the-minute totally flexible manufacturing plant where anything could happen anywhere' (Moore, 1993). The factory -in Cologne, Germany- has been built through seven phases, over a period of 17 years. The 4,500 sqm block was completed by N. Grimshaw & Partners in 1992. Since then, Bryden Wood Associates have been in charge, reaching nearly 20.000sqm (Fig1).

The whole building, made of four square blocks, was able to be built by halves. An open-lattice steel mast structure enables columns free spaces and the external wall panels can be changed by the simple removal of clamps. The services are easily accessible, located overhead to avoid disturbing the manufacturing process (Fig2). The building has a high degree of standardisation and re-usability of components for a greater adaptability. Igus is a further step on the concept of flexible, panelled and wide-span buildings designed by Grimshaw & Partners, such as the assembly plant for Herman Miller built in 1976, with a cladding system completely demountable and a servicing system reached by catwalks, or their Distribution Centre from 1983, designed for future expansion and uses change.

Figure 2: *Internal space empty & with machinery (Grimshaw & BWA)*

Technical features: Structure, Envelope and Services

Structure

The whole building is made of four square blocks of 67.50m x 67.50m -including 6 bays of 11.25m x 11.25m each- and 8.40 m high. The factory is able to be built by halves, once the first block is completed. An open-lattice steel mast structure enables spans of up to 33m and support –hanged to the cables- the main steel structure of the roof and GRP domes. The domes - 6m diameter and 1.5m high- are manufactured in 3 pieces to fit the size of a container lorry. The north-facing elliptical glass lights provide daylight and natural ventilation through opening windows (Fig 3). The first floor walkways and moveable offices ‘pods’ are free standing internal structures. The walkways are located at the cross axes of each block and form the main services and circulation route through the building.

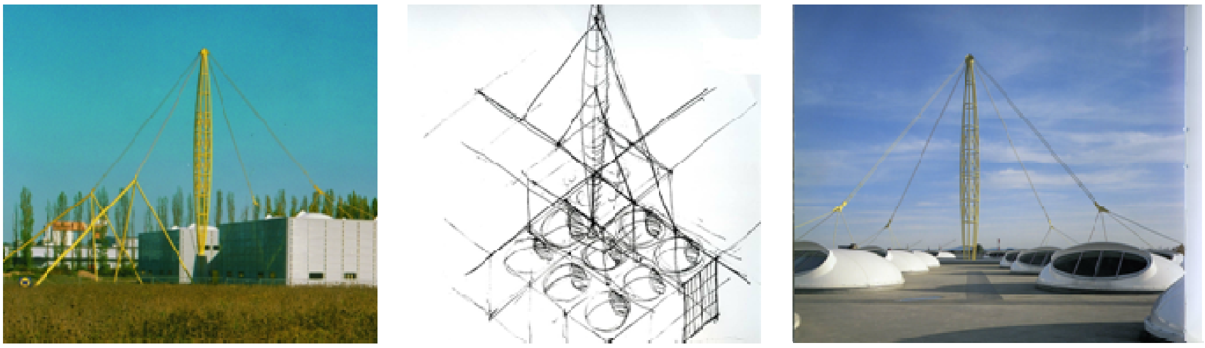

Figure 3: *Pylon structure allows extension by halves. Conceptual sketch of the structure (Drawing by Grimshaw). Steel pylon & cables support the roof structure (Grimshaw)*

Envelope

The grid used for the cladding -2.25 m wide x 1.05 high- is coordinated to the square blocks and bays dimmensions (Fig 4). All the elements of the cladding are held in place by satin-silver naturally anodised aluminium clamps secured into composite mullions. The mullions are fabricated from standard shelving uprights bolted to steel flat plates that have been reinforced to span the full height of the facade with 60 mm diameter circular hollow sections. Internally, shelves, light switches or fire hydrants can be fixed directly to them.

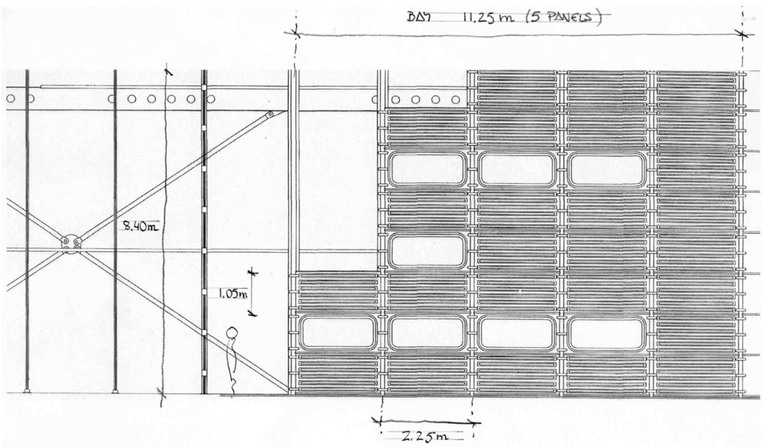

Figure 4: *Cladding system & building grid coordination (Fuster)*

The system can incorporate a variety of finishes including solid insulated aluminium panels, opening insulated double-glazed windows, louvre panels -for ventilation & services penetration-, escape, personel and loading bay doors (Fig 5). They can be easily removed and interchanged by loosening the clamps and turning them through 90 degrees. The façade has been designed to respond to any change into the factory layout and replacement could be carried by unskilled labour. The company bought the panels moulds -made by brake press-, to facilitate and reduce the cost of later extensions.

Figure 5: *Cladding system. Internal & external views (Grimshaw)*

Services

The services run along with the first floor walkways. They are located overhead, including the pumped drainage. There is no need to match fixed connections in the floor. The conducts are exposed to facilitate the plug-in, maintenance and frequent changes (Fig 6). Each pod has its own services box, which can be plugged into the building's overall system through flexible ducts. The mechanical ventilation has been minimised. With air entering through the walls at low level, the opening rooflights create a stack effect that draws air through the entire building. There is no need of heating as the internal space is constantly at 24 degrees celsius.

Figure 6: *Services exposed along the walkways (Grimshaw& BWA)*

Partitions

The client did not want walls and there are no partitions at all in the whole building, which has been an added difficulty, due to the fire regulations. Sprinklers and water curtains were installed to prevent fire spreading, as client wanted to keep the space very open. The only existing 'close spaces' are the moveable pods (Fig7). They contain general administration offices and can also house shower rooms and toilets. The space directly beneath -a buffer zone between the noise of the factory and the administration areas above- forms an area where quality control, research and development can be carried out .They can be moved over a weekend at a short notice across the concrete slab to be closer to the operations going on in the factory. All furniture is custom made, utilising the same Unistruct cold rolled channels of the cladding, consisting of several components that can be reconfigured as required.

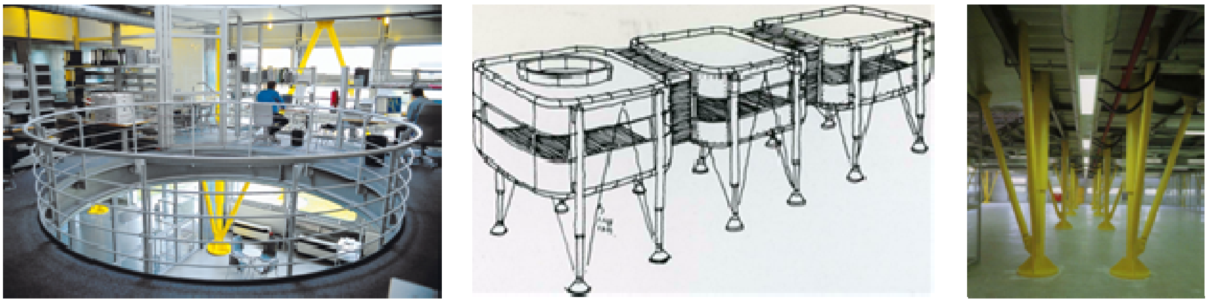

Figure 7: *Moveable pods (Grimshaw. Drawing by Bryden)*

Adaptations to the building

The building has facilitated the clients' long term plans, thanks to the adaptable design approach, by allowing all the changes and providing the ability to grow in different phases. The grid adopted coordinates the abundance of moving, portable, changeable and repeatable parts, which has a clear value in giving flexibility to the whole scheme. It also has enabled a neater appearance of the internal space and prevented from the chaos of such a changing, busy and noisy factory. The repetition of parts has also helped through all the process and the extensions have been easier due to the previous experience.

The scheme has allowed the frequent changes to the manufacturing processes, production lines and machinery, to suit the variant demand without big disturbance or major cost. It has also facilitated the expansion of the business and growth of the factory over the 17 years, from 4.500 to 20.000 sqm (Fig 8). Changes to the façade have been also frequent to suit the internal layouts and needs of natural light. The exposed services have been easy to maintain and change, especially now that the factory is full of machinery and cables. The building is well maintained. Ceilings and roof domes are cleaned daily and the internal space looks always as new.

The pods -designed to change from place to place, to remain close to the ongoing operations in the factory- have almost never been moved and remain now static, as the space is completely full of machinery. In fact a new extension is actually undergoing and a factory building of more than half the actual will be linked to the existing four squares. There will not be anymore pods and the offices are going to be fixed. At this new stage, some areas could have been improved, but finally not radical changes have happen as the new building must keep the ability to interchange its parts with the existing one. The biggest constraint has been again the fire regulations to enable big open spaces, solved by means of sprinklers, water curtains, automatic shutters and a big deal of discussion between the company and the planning responsible. The cost of constructing the building has not been cheap however; it has been a very good investment and given the company a significant value by allowing them to accommodate the ever changing business needs and grow when necessary.

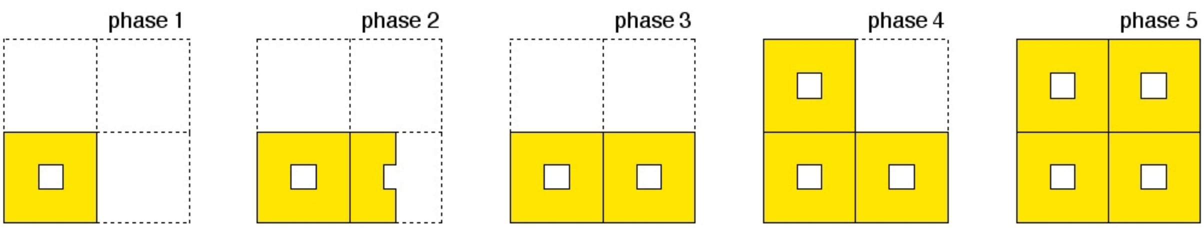

Figure 8: *Igus factory growing sequence (Grimshaw)*

C& B ENGINEERING DEPARTMENT, LOUGHBOROUGH UNIVERSITY, UK (2)

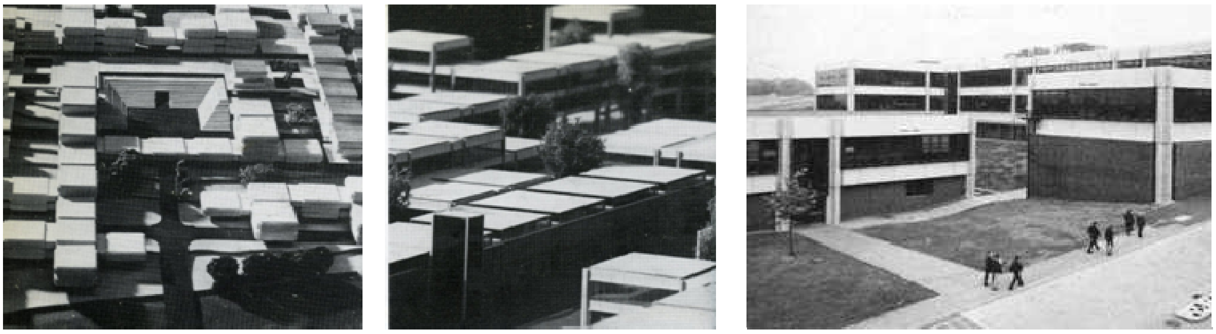

Figure 9: *Loughborough University Master Plan Model and first buildings, 1966(Cantor)*

Description

Based on a common grid, the master plan of Loughborough University was established in 1966, to ensure order and continuity in the development of the campus, as well as allowing flexibility to met future requirements (Fig 9). Each building was planned as a universal adaptable design, able to change to varying teaching categories of use, including workshops, research laboratories, specialist and non-specialist teaching spaces and staff offices. The whole scheme was coordinated at campus and building level, by standardizing the structure, partitions & services pathways dimensions (Fig 10&11). These dimensions, used throughout the campus and building design, meshed together to form a tartan grid.

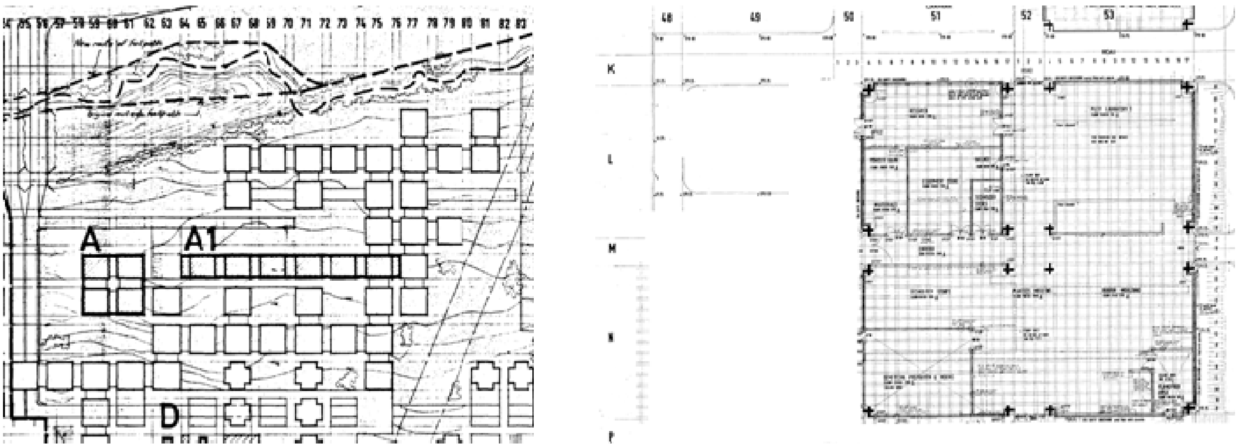

Figure 10: *Loughborough University master plan & building 'Tartan' grid (Arup Associates)*

Arup Associates designed a square block as universal adaptable volume, linked by modular connections (Fig.10).The size of units was chosen to maximise natural lighting, while allowing maximum open space for various plan arrangements. The shape enabled extension of similar units on any of the four sides. A partition system was developed to facilitate easy changes and the buildings included all services requirements thanks to the deep structural floors. Vertical rising ducts could be accommodated in nearly any position, to suit unknown changes in technology and needs. The Civil Engineering Building was the first to be designed and constructed in 1969, using four square units of two floors.

Technical features: Structure, Envelope, Services and Partitions

Structure

The building is pre-cast concrete, made of four 53ft3in square units (17.00m), linked by a 10ft6in space (3.00m) between adjoining squares, for vertical circulation as staircases. The structure includes four corner columns supporting a girder system, spanning the whole dimmension, allowing a clear span of 50ft (15m). The floor height is 10ft (3m). The ceiling is made from reinforced concrete panels supported on the bottom beams of the floor girders. The structural grid follows the master plan 'Tartan' grid (Fig 10&11).

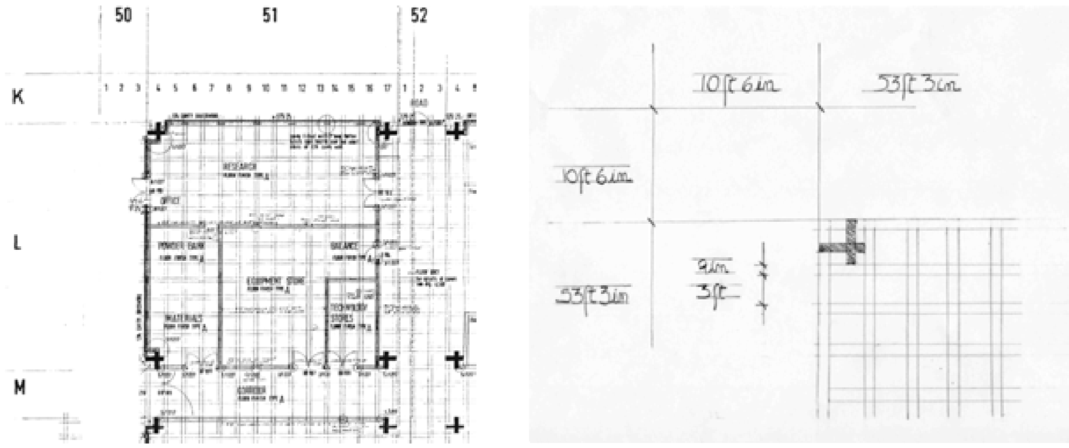

Figure 11: *Tartan grid at structure & partitions level (Fuster)*

Envelope

At first floor level and above, the external wall is pre-cast concrete cladding. A glazing system was developed to suit the buildings, with windows mullions following the planning grid to allow partitions to be fixed. The entire exterior wall was designed to be removed if an expansion was required.

Services

The service provision allowed flexibility in initial planning and in future rearrangement, with ease of modification and replacement. The 5 ft large service void (1.50m)-enough to crawl through-, provided access for maintenance with the minimum of inconvenience to the users. All services requirements -common and specialist services for the laboratory accommodation- run throughout this space in bands, rather than lines, related to the planning grid-partitions-(Fig11). Service penetration 6in square holes (0,15m) were provided at the cross points of the partitions bands, in each direction of the grid (Fig12).

Figure 12: *Two53ft3in square units linked by 10ft6in strip. Partitions grid pattern of 3ft+9in cast into the soffit of the ceiling panel. Service void & 5ft deep girders (Beadle, Austin)*

Partitions
After examining all the different accommodation requirements, a modular system was developed to facilitate easy changes. The partition grid followed a network of 9in wide lines (0.20m), spaced 3 ft apart (0.90m), running in two directions, which is coordinated to the structural and master plan grid (Fig 11&12). The thickness of 9in suits the various types of walls needed. The basic module of 3ft plus the 9in satisfied the range of room dimensions.The pattern was visible in the original floor covering and still depicted in the concrete ceiling panels, for ease of replacement.The panels were easy to assemble and reassemble, capable of being removed individually, with cover strips to keep them in position. A wide variety of finishes could be applied and accessories easily fixed. The pannels satisfied the fire requirements and acted as a good sound insulation.
Note: All the Imperial dimmensions converted to metres in this chapter are aproximated.

Adaptations to the building
The master plan -designed to enable the university campus to expand, change and even shrink if necessary- has ensured order and continuity while building new facilities at high and detailed level. The universal adaptable block addressed the space and functional requirements for each teaching space, without been tailored to any one function in particular, to avoid a quick out-of-date. A previous and cautious study of all the differences and common elements has been key to reach this adaptable solution and facilitate the internal changes. The layouts have been easily modified, thanks to the big clear span, modular partition system, planned service pathways and cladding mullions, all of them coordinated by the same grid.
Along with the 'Tartan grid', the high degree of standardisation and re-usability achieved - including floor units, columns, external walls, ceiling components, partitions (doors, cupboards, etc.) and service ducts- has contribute to the adaptability.

Figure 13: *New extension, 2006(Swanke Hayden Connell). Atrium to link new & existing building. Open plan space created in existing building (Beadle)*

The Civil and Building Department was also designed to enable extension easily on any of the four sides. After nearly 40 years, when the building reached its capacity and space for additional academic staff was needed, it was not extended as planned. In 2006, and after an architectural competition, a three-storey curved extension –probably a more appropriate design for a contemporary building- was linked through an atrium to the rectangular two-storey existing volume, to provide cellular offices (Fig13).

SILK STREET OFFICES, LONDON, UK (3)

Figure 14: *Aerial view of the two Multi-storey buildings and façade(Madden)*

Description

Two existing multi-storey buildings constructed in 1982, Milton and Shire House, were converted in 1996 to form one unified high-quality legal office to serve a single client, in central London, -a site surrounded by high rise constructions, close to the Barbican centre (Fig 14). The main reason for the refurbishment of the two office blocks was to create a high degree of flexibility to enable internal reconfiguration quickly at a short notice, whilst retaining acoustic and visual privacy and a sophisticated level of M&E and IT services.
The project comprised major refurbishment work of the 56.000 m2 of both office blocks.
The buildings were basically stripped back to their original concrete frames, with the precast concrete floor and roof slabs being retained. The works included the construction of additional floor space at the 5th, 6th and 7th floors of one of the blocks (Shire House) and the replacement of external cladding and services. It was estimated that the demolition and refurbishment works cost approximately 75% of the cost of a comparable new building. The building since have been able to continually adapt to suit new requirements at very short notice with a very limited amount of time. It represents a very interesting example of the benefits of employing and accommodating both an 'in-house' maintenance team and workshops to carry out preventative maintenance, on-going maintenance items and quick adaptations to fulfill new business requirements through the use of simple and cost effective solutions, extending its potential life expectancy.

Technical features: Structure, Envelope, Services and Partitions

Structure

The original buildings consisted of reinforced concrete frames, in a grid of 6.00 m x 7.50 m, which were stripped out during the refurbishment. The existing concrete foundations and reinforced concrete frames were retained together with the existing reinforced concrete floor and roof slabs. The limitation of the floor-to-floor height for additional service provision and acoustic treatments was overcome by the original 65mm thick floor screeds being replaced with 12.5mm 'Isocrete', with glass fiber mat reinforcement, reaching a new height of 3.40 between floors. This allowed both ceiling and floor level concealed services, which facilitates the continuous changes and new layouts of the floor plan.

Envelop

The external fabric of the building was completely stripped. The new stove-enameled aluminum cladding runs independently from the structure and the window mullions are used to locate the partitions.

Services
Most of the services were replaced providing new technologies and air conditioning, including reconfiguration of toilets and spaces for services risers.
Partitions
The office partitions generally coincide with the columns of the existing concrete grid or the window module. They consist of metal studs framework with insulating quilt in between and standard plasterboard panels to both faces. Materials are low-cost, easily maintained and readily available with simple construction details.

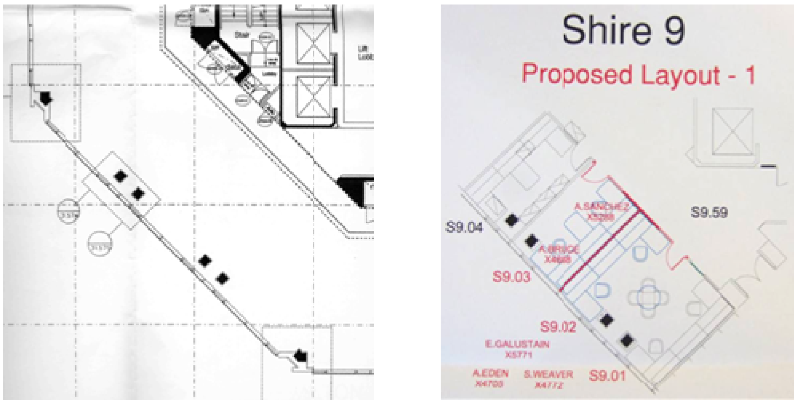

Figure 15: *Shire S9.01 subdivided to create two new offices in August 08 (Madden, Fuster)*

Adaptations to the building
Since the major refurbishment of these buildings was carried out in 1995-96, there have been numerous alterations to the layout of the office accommodation. Generally the office layouts are of cellular nature- due to the confidentiality of the legal work undertaken in them- with some limited use of shared open-plan offices, often as a general extension of the circulation areas. Visual privacy is also an important aspect of the design. The layout of the offices changes on a regular basis to accommodate new staff and changes in working relationships at very short notice. A common alteration will involve an office being sub-divided into two new ones. (Fig 15) The alterations are carried out by the 'in-house' maintenance team and include the provision of new doors, partitions and furnishings. A simple new partition is formed on site to sub-divide the offices using standard metal studding for the framework fixed to the window mullion and the corridor wall partition framework. Standard plasterboard panels are provided to both faces of the metal stud partition with insulating quilt in between. The joints between the panels are taped and sealed and the partition finished with two coats of emulsion. Skirting boards are either flush or self-finished to facilitate ease of redecoration at a later date (Fig 16). Since both ceilings and floor are accessible to gain access to services at virtually any desired location, the office layouts are extremely flexible. Services are easily accessible through removable carpet tiles -laid on top of metal-faced chipboard tiles- located in a grid on a raised metal framework. The standard ones can be substituted with a service access tile. The whole operation takes between two to three days and could be carried out with other maintenance items over a weekend to ensure minimal disruption to the work. The method is a simple and cost effective solution to continuously adapt the building to fulfill new requirements and extend its potential life. The use of low-cost, easily maintained and readily available 'standard' materials with simple construction details makes an invaluable contribution to adaptation of the internal space, as does the 'in house' maintenance team.

Figure 16: *Partition showing metal frame into window mullion and ceiling grid (Madden)*

LESSONS LEARNT

The strategic principles to approach the design and implementation of a successful quality adaptable non-residential building, are common to each of the three case studies described - Igus factory (1), Civil & building Engineering Department (2) and Silk Street (3)- :

- Focus on the client/business requirements of adaptability: :
  - (CS1) The company has unpredictable and ever changing production needs
  - (CS2) The design of the building should allow flexibility to met future teaching requirements
  - (CS3) The office space should enable frequent internal staff changes and quick relocation
- Define the scope of adaptability to provide the client/business needs:
  - (CS1) Totally flexible manufacturing plant, able to be re-configured within a short period of time and extended
  - (CS2) Universal adaptable building able to change to varying teaching needs
  - (CS3) High degree of internal space flexibility at a short notice
- Choose the technical features to enable the adaptability
  - (CS1) Str-Big span structure, E-Totally flexible envelope, S-Exposed services concentrated along pathways, P-Open space, no partitions
  - (CS2) Str-Big clear span, S-Deep service void & planned pathways, E-Cladding mullions coordinated with partitions grid, P-Modular partition system
  - (CS3) Str-Existing, E- Window mullions designed to locate the partitions , S-Easily accessible through removable tiles at ceiling & floor levels, P-Easy to remove & erected, cheap standard materials

Other important points:

- Design needs to address the lifecycle -not just the first use- (CS1,2&3)
- The range of solutions offered by the adaptable building must been known and carefully studied form the start (CS1,2&3)
- A grid suitable to the function -if defined at the start of the project- simplifies the work, enables the components and changes coordination, gives coherence to the process and allows the growth and changes in a planned way (CS1,2&3)
- A high degree of repeatability and reusability of the components will contribute to make the building more adaptable (CS1,2&3)

- The use of easily maintained and readily available materials with simple construction details can make an invaluable contribution to building adaptability (CS1,2&3)
- Sometimes the adaptable planned characteristics will not be used due to the change of taste and availability when needed (CS1&2)
- Refurbishment of existing buildings adding flexibility can have substantial benefits in terms of time, cost and assist in extending its useful life (CS3)
- A service strategy allowing access, replacement, maintenance and up-date of the different parts is basic for a successful adaptable building (CS1,2&3)

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