information paper

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Five-storey timber-frame hall of residence

a reconstruction case study

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This Information Paper describes the design and construction challenges for a replacement student hall of residence on the esplanade of Aberystwyth. The case study focuses on key features of the project with special attention given to the 5-storey timber-frame structure. The building was required to re-house over 100 students displaced by fire damage and had to be designed and built in the shortest practicable time for economic reasons. It also had to meet demanding architectural, technical and conservation requirements.

On the night of 4th November 1998 a fire started in a hotel room along the esplanade of Aberystwyth. The ensuing fire spread through the roof compartment of the hotel to the adjacent Caerleon and Pumlumon student halls, causing such devastation to the eight-bay terrace block that the solid wall construction was deemed to be unstable following a post-fire evaluation of the damage. Although the building structure did not collapse as a result of the fire, a structural assessment recommended that the Grade II listed building be demolished, including the stonework façade. Listed building consent was granted for the demolition with a 106 agreement issued for the reinstatement of a replica façade, including matched windows and roofline, during reconstruction of the building.

Construction of the replica façade would later produce design and technical issues to be addressed by the architect and contractors, but although this was an important feature of the project, *the overriding design constraint for the replacement building was to minimise the time for construction*. This constraint was identified by the University who covered the cost for the temporary housing of 100 students in local rented accommodation and hotels.

The morning after the student halls fire

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Key features of the project

- Five storeys over basement
- Listed façade requiring height and feature-matching
- Roof line and chimney styles to be matched
- 'Fast-track' re-occupancy required by the University and Insurers
- Client, Architect and Main Contractor partnering with tendered sub-contracts
- 'Environmentally friendly' materials and construction issues
- Demolition and removal of fire-gutted remains
- Varying site levels (level at front, sloping mid and rear)
- Very restricted site (limited materials storage)
- Two parallel, linked blocks to maximise site utilisation
- Series of student 'family' flats (2–8 bedrooms)
- Robustness appropriate to student usage
- Minimisation of energy consumption
- Low-energy box sash timber windows
- Enhanced sound insulation

To reduce the total construction time for the replacement building, a framed structure was identified as providing the fastest construction time over more traditional block wall construction. Of the different possibilities for framing members, timber-frame construction was chosen by the Client for its low environmental impact, ease of erection, low running costs and sustainability credentials. Gwalia Housing Group has a very robust environmental policy and where possible commissions developments that use sustainable technologies with low environmental impact[1]; most of its housing developments incorporate timber-frame construction for the building structure.

The client brief

Credits

Client	Gwalia Housing Group
Architect	James-Jenkins of Aberystwyth
Quantity Surveyor	Shaun Condron Partnership
Main Contractor	Cowlins Ltd
Structural Engineer	ATEB Consult Ltd
Timber-frame Contract	Prestoplan Ltd
Timber-frame Design Consultant	TRADA Technology Ltd
Contract type	JCT (with Partnering)
Total occupancy area	3500 m^2
Total redevelopment cost	£3.7M

Although Ceredigion County Council owned the original building freehold with the University of Wales Estates Department as leaseholder, Gwalia Housing Group were sole owners and clients for the new building.

Funding for the building reconstruction came from the building Insurers, whose loss adjusters participated in the formulation of the client brief. The main concerns expressed by the client were:

- replicating the front façade in accordance with the 106 agreement,
- minimising road closures for delivering building materials to a constrained site with minimal storage facilities,
- provision of a computer network linking each study room to the University Intranet,
- sound transmission between flats and study rooms,
- robustness of the building structure and fabric,
- thermal efficiency and weathertightness of the building on a highly exposed site (sea front esplanade),
- environmental impact of the building construction,
- contract duration for completion of the re-constructed building.

Front façade of the original student halls building

The reconstructed front façade and neighbouring building on the right

The last of these was addressed primarily by choosing a framed construction for the wall inner leaf in favour of more common block work construction. This was anticipated to reduce the contract period by eight months. Other performance criteria expressed in the brief are discussed later in sections covering the Design solutions and Construction issues.

Why a timber frame was specified

The utilisation of sustainable technologies that involve a high degree of prefabrication are central to the initiatives of 'Agenda 21' and 'Rethinking Construction', two current challenges facing the construction industry. Timber-frame construction is ideally suited for addressing both of these initiatives and is established as the 'material of choice' for the Gwalia Housing Group.

Although the client had gained a vast experience of timber-frame construction for low-rise structures (two to four storeys), a Timber-frame Design Consultant was contracted to advise on solutions for different regulatory requirements for the five-storey timber frame structure. Additional benefits of timber-frame construction for medium-rise structures emerged during the duration of the project from consultations which enhanced the case for using timber frame.

A benchmarking study[2] conducted as part of the TF2000 project, provided a direct comparison of 'stretch performance targets' based on the current industry practice for the following criteria:

- *lead time* for production of construction drawings,
- *site production rate* for the structural framework,
- *cost of structural frame construction,*
- *quality of construction.*

The results of this benchmarking study compared with existing benchmarks for other construction types indicated that the timber-framed solution was the most likely to be erected within the tight time and financial constraints. Comparison of the benchmark targets for steel-, timber- and concrete-framed structures in this study (summarised in the Table below) indicate that the cost of framing in particular would be the lowest with a timber structure though the site production rate would be greatest for a steel structure based on the framing elements alone. Obviously a timber-frame structure also provides for the fixing of internal lining which has a cost benefit.

In reality, the overall cost and speed of construction for the building was expected to be even better with timber frame since the dry shell offered by a timber-framed structure would allow works to proceed without delay on internal services and dry lining. Internal work on concrete- or steel-framed structures cannot proceed until the compartment walls are in place.

The lead-time and quality of construction were considered and expected to be similar for all three construction types and would depend mostly on the contract partnering and on site supervision.

Design solutions

One of the key features of the building construction in terms of regulatory compliance was the use of a timber frame for five storeys above a concrete basement. This is not in itself a unique feature of the project since many other timber-framed buildings have been constructed to five storeys, indeed the acclaimed TF2000 building[3] at BRE Cardington was constructed to six storeys. However, in common with any construction method involving a variety of materials, constructing medium-rise timber-framed buildings (5–8 storeys) will impose more regulatory constraints and construction solutions. Many of the design solutions for medium-rise timber-frame buildings have been tried and tested on the TF2000 building and are now being adopted by the industry, exploiting the potential savings from increased pre-fabrication. The technical solutions to regulatory issues adopted for this building are discussed in the following sections but are not intended to be prescriptive or even normative: they are merely examples. Other issues and solutions concerning reconstruction of the listed building are also discussed.

Structural stability

In the UK, timber-framed buildings are traditionally built using a structural layout generically termed 'platform frame

A comparison of benchmark targets for different structural frames[2]

	Steel	Concrete	Timber
Structural frame cost	£79/m^2	£61/m^2	£60/m^2
Site production rate	909 m^2/week	333 m^2/week	750 m^2/week

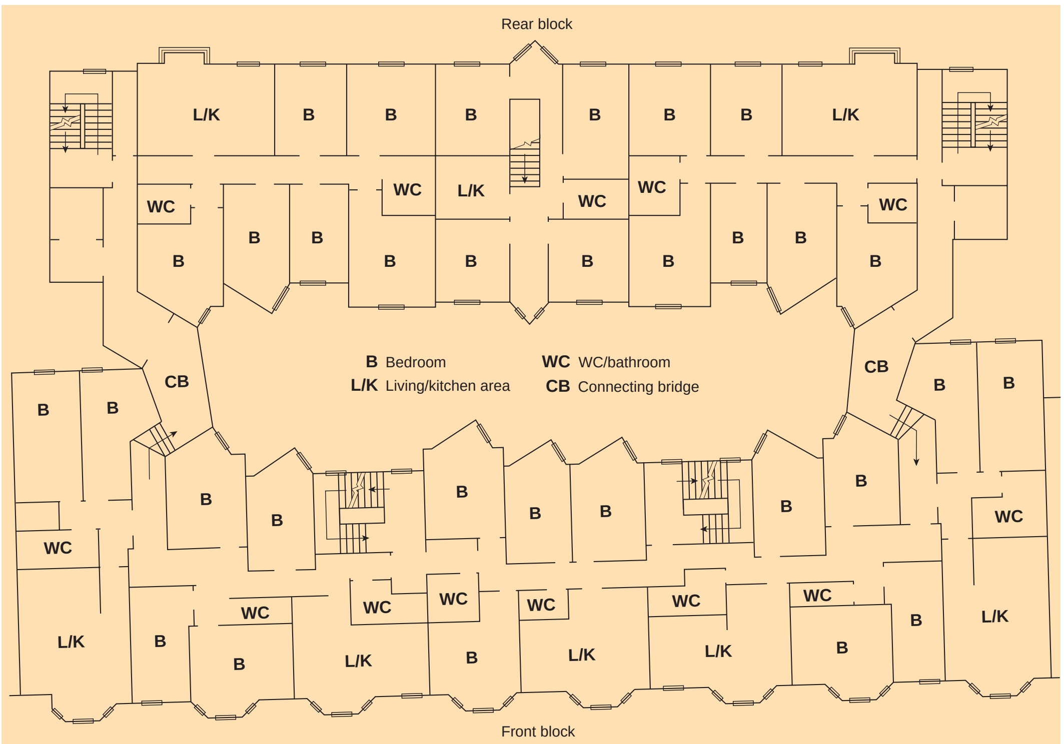
construction'. This construction technique uses connected wall panels to form the supports for the floor panels which in turn form a working platform for constructing the next storey of wall panels, and so on. The stability of a complete structural system for resisting lateral loads is provided by diaphragm action of the walls and floor panels. Although more traditionally used for low-rise buildings, this construction technique can be easily adopted for medium-rise structures, as was the case for the student halls building. Individual flats are built using the principles of compartmentation for minimising acoustic transfer. They are interconnected to provide continuity to the structure and ensure the overall stability of the building.

Normally this type of structural form is designed to resist wind loads transferred from the cladding and will support all of the vertical imposed and dead loads. Although stone, brick or blockwork cladding supports its own self weight, any windows are normally supported by the structural timber frame with movement gaps provided between the window frame and cladding. In the case of this building, the type of timber bay windows, as required in the 106 agreement for reinstatement of the façade, proved to be exceptionally heavy and offset from the timber frame in the deep stone façade as shown in the photograph opposite. Since the detailing of cantilevered framing required to support these windows was not practicable and may have impaired the structural stability of the bay, it was decided to support the weight of these windows on the stone cladding. Any movement anticipated between the cladding and timber frame was designed for by special detailing of the internal sill and architrave surround using 'sliding' connectors to limit any out-of-plane movement.

Front façade detail

Fire safety

This building complies fully with the statutory requirements of Approved Document B (1992) for fire resistance and the egress of occupants. Adjacent flats are protected with two layers of plasterboard comprising 19 mm plank and 12.5 mm plasterboard fixed to all party walls and internal load-bearing wall panels, thus providing one hour of fire resistance. External walls are protected to the same standard where



Schematic plan of the new building at first-floor level

non-load-bearing walls are provided with half-an-hour of fire resistance. Other routes for fire spread such as through the floor, ceiling, wall cavities and service ducts are also protected for one hour's resistance using plasterboard and mineral fibre fire stops in the cavities. In addition to the passive fire protection, fire detection is provided to the building with an L1-type system.

To ensure safe alternative means of escape from any flat, the architectural layout included two features additional to the five protected stairwells provided in the two accommodation blocks. Firstly, walkways were provided, bridging the gap between the front and rear accommodation blocks at first-floor level and above, and can be accessed by anybody entering or leaving the building. The second feature, a protected corridor provided on upper storeys of the front accommodation block, linked adjacent flats but to maintain security between flats they could only be accessed with a break-glass-key for use in emergencies. All of these features are solutions especially adopted for this building and are not specific to timber-frame construction.

Disproportionate collapse

Requirement A3 of the Building Regulations (England & Wales) 1991 applies to all buildings with five or more storeys and states that 'in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause'. There are generally two accepted methods for demonstrating compliance; the key element method and the robustness method. Experience and tests have shown that timber-frame buildings exhibit sufficient robustness, especially cellular layout and platform frame type constructions, such that if a structural element such as a wall panel is notionally removed, the rest of the structure is capable of bridging over the gap. To achieve this performance criteria a continuous rim beam is provided around the perimeter of the timber frame at each floor level and is designed to support the load normally taken by the notionally removed panel, albeit in a substantially deformed condition. Wall panels above the rim beam also aid the transfer of loads by acting as a deep beam. Sufficient horizontal and vertical tying of internal structural panels is already provided in the structural make-up without the addition of rim beams.

This accepted method of designing timber-frame buildings to meet the disproportionate collapse requirements has been proven by impressive tests results on the TF2000 building; the observed building deformation was substantially better than deflection criteria for notionally removed panels. The same design principles were adopted for the student halls building.

Differential movement

With all structural and non-structural components of a building, detailing should allow for any potential movement across connections, known as differential movement. This is of particular importance in a timber-frame building where occupancy heating causes the timber to shrink across the grain and therefore reduces the overall height of the construction. Other building components such as brick or stone cladding may increase in height during the building's design life due to both reversible and irreversible moisture-related movement and thermal expansion. This differential movement between the cladding and timber frame and even between the timber frame and internal stairwells of mixed construction must be allowed for in design.

Of the three different types of cladding adopted for the replacement student halls building, the front limestone façade posed the most onerous design case for differential movement. Although a negligible amount of irreversible and reversible moisture-related movement would be expected in-service, an allowance for the thermal expansion of the limestone cladding was considered necessary.

The majority of any vertical movement in the timber frame can be attributed to the following types of movement for timber loaded perpendicular to the grain:

- shrinkage,
- compression,
- bedding-in.

To help reduce the total movement in medium-rise timber-frame buildings, it is normally the case that one or more of the following counter measures are adopted:

- reduce the total depth of timber loaded perpendicular to the grain,
- specify timber with a lower moisture content to reduce the amount of shrinkage,
- specify engineered wood products that have a greater bearing stiffness.

All of these solutions were incorporated to different degrees to control differential movement in the student halls building. Pressed metal web floor joists helped to reduce the depth of timber loaded perpendicularly and were in turn supported on laminated veneer lumber (LVL) rim beams, which are manufactured with a low moisture content.

These specific solutions enabled flexible wall ties to be used for connecting the timber frame to the cladding.

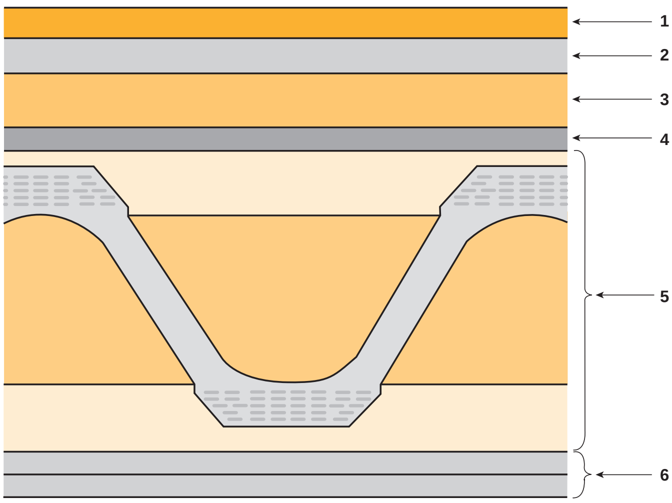
Sound transmission

One of the main concerns expressed in the client brief was the acoustical insulation between student flats and bedrooms which was expected to greatly influence the level of comfort experienced by the occupants. To achieve a superior level of acoustical performance detailing of the wall and floor construction would need to provide significant improvement on current building regulations. An enhancement of 3 dB to the sound insulation is generally accepted as significantly noticeable and was included in the following sound insulation target values for this building:

- airborne sound insulation for walls — 55 dB (min)
- airborne sound insulation for floors — 54 dB (min)
- impact sound transmission for floors — 59 dB (max)

Standard timber-frame wall construction can easily achieve high acoustical performance standards and was further enhanced for the Caerleon and Pumlumon Halls by additional sealing properties of the blown cellulose fibre insulation.

Evidence from tests conducted on the TF2000 building provided justification that the detailing adopted in the student halls would be sufficient to meet the enhanced acoustical performance standards of the student halls.



1 18 mm moisture-resistant chipboard. Glued tongue and groove edges
2 19 mm plasterboard
3 25 mm rockwool sheet
4 15 mm OSB, Type 3
5 Proprietary metal webbed timber beams with 100 mm glass wool quilt between
6 Two layers of 12.5 mm plasterboard

Sectional drawing of the floor construction

Thermal efficiency

The conservation of fuel and power is a statutory requirement of the Building Regulations (England & Wales) 1991, which provides guidance on the thermal efficiency of the building fabric in Approved Document L (1994). On an exposed site such as the Aberystwyth esplanade the thermal insulation provided to external walls and the roof of the new student halls building will contribute significantly to the conservation of fuel used for space heating. Enhanced thermal insulation to the external fabric, beyond that recommended in the Building Regulations was proposed for this building to meet client requirements.

The seafront external wall construction provided a U-value of 0.23 W/m^{2}K, almost a 100% improvement beyond the recommended value provided in the Building Regulations. This equates to a similar thermal performance claimed by some ultra-low energy homes[4] and was achieved with the following building elements:

- 2 layers of 12.5 mm plasterboard,
- 140 mm × 38 mm timber studs with sprayed cellulose fibre insulation,
- structural sheathing,
- 50 mm cavity,
- 100 mm limestone cladding.

Timber double-glazed windows with low emissivity were used throughout the building to maintain a high level of thermal insulation, again beyond that recommended in the Building Regulations. This was also the case for the roof insulation which included two layers of 100 mm mineral wool above flat ceilings to help achieve a U-value of 0.19 W/m^{2}K.

Additional features of the building that benefited the thermal performance and energy consumption were:

- increased solar gains from south-facing windows,
- active stack ventilation,
- low energy lighting,
- central gas-fired boiler for heating and hot water,
- energy management system for remote monitoring of electricity and hot-water usage.

Durability

With any construction the designer has to ensure that the materials used in construction are suitable for their intended purpose. This also translates into site practice where good detailing must be constructed correctly to ensure that the materials perform as intended. Timber-frame structures are no different to any other building in that good detailing and good workmanship are essential to the durability performance of the structure.

The student halls building has been designed and constructed with close attention paid to 'best practice' for timber-frame construction. For instance, the external timber-frame wall has sufficient cavity ventilation and is designed as a breathable wall whilst avoiding interstitial condensation. A breather membrane was added to the sheathing to protect the timber frame from rain during the construction period.

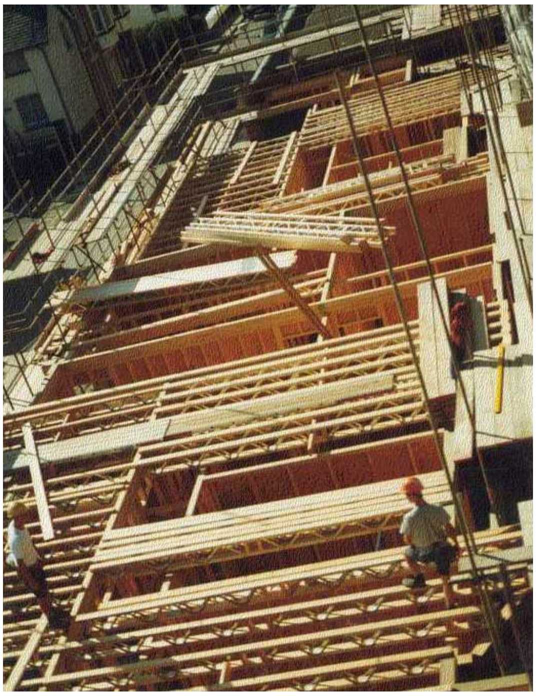
Softwood timber windows exposed to the elements have been vacuum-impregnated with preservative in accordance with best practice and British Standards to provide at least a 30-year service life.

Construction issues

The reconstruction of a building within a townscape invariably encompasses additional constraints on the storage of construction materials, site access and other construction issues. In the case of the student halls building, such constraints not only affected the site management but also fundamental aspects of the building design and increased the benefits of adopting a timber-frame structure.

Construction process

Once the site had been cleared and construction of the concrete basement was completed, erection of the timber frame started. Pre-fabricated panels delivered to the site were craned into position to help achieve a high level of productivity and minimise the effect of road closures on the local community. During the erection of the timber frame other tradesmen began installing services and insulation, and lining the formed compartments on lower floors thus reducing the total contract period for the building construction. Once the timber frame and roof structure had been completed, construction of the external cladding started. *Many of the secondary fittings, floating floors, services and even utility fixtures had been completed by the time the cladding was completed*, highlighting the added benefit of timber-frame construction for reducing the total contract duration.



Floor construction using metal web timber beams

Site restrictions

Access was restricted to the front and rear of the site, with very limited space on the plot for the storage of materials. It was soon realised during the design phase that there was insufficient space for storing concrete blocks to be used in construction of the building or even cladding. This not only reinforced the decision for using a timber-frame structure but also encouraged the architect to consider alternative forms of cladding. Timber lath cladding with rendering was specified for parts of the rear block of flats which although it requires additional insulation to achieve the same thermal performance as the blockwork counterpart, greatly reduces the requirements for site storage and is much easier to handle and quicker to erect. Other types of cladding adopted for the rear façades of the building included a patented fibrous board with weather shielding.

Robustness of fixings for occupants

Potentially robust treatment of the building fabric and facilities in the student accommodation had to be considered in the design to minimise ongoing maintenance. Serious consideration in the design stages and later testing of the construction and fittings helped to ensure that all parts of the fabric and fittings were capable of withstanding robust treatment. For instance, in the design phase, internal wall linings were increased from the nominal 12.5 mm plasterboard required for fire resistance to 19 mm wallboard that can withstand much greater impact loads. Bathroom and kitchen fixings were also designed to be more robust. However, during the fixing of bathroom sinks, testing of the sinks highlighted that if the students sat on the sink at any time the support offered by the initial wall design was insufficient. This problem was easily rectified at an early stage by increasing the number of studs and cross supports in the timber frame and re-lining the wall panel. This could be conducted without the use of props and did not affect the final appearance or overall construction period.

Overall impressions

The new Caerleon and Pumlumon Halls were completed in timber frame on schedule towards the end of March 2000, in time for students to move in at the beginning of the summer term, 2000. This could not have been achieved using blockwork construction, which was anticipated to take an additional eight months. Partners to the project were impressed by the speed of construction, compared with experience of other forms of construction, as well as other additional benefits of timber-frame construction highlighted in this document. The architect to the project, Harry James summarised his experience of medium-rise timber-frame construction as follows:

'Whilst we have considerable experience of domestic-scale timber-frame construction, this has been our first experience of a multi-storey development in timber frame. Having addressed the technical issues such as differential movement and disproportionate collapse, the principles are then similar and the end result is equally rewarding in terms of efficiency, speed of construction and easing the facility for early completion of internal trades'.

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