A4.1 Case Study: The TF 2000 Project, England

A need to review the existing information and construction requirements affecting timber frame medium rise buildings in response to increasing land shortages formed the basis for the development of the TF 2000 Project. A 6 storey timber frame experimental building, the first of its kind, was constructed to investigate both the performance and economic prospects of medium rise timber frame buildings in the UK.

Until recently, the 1991 fire regulations in the UK limited timber frame buildings to no more than three storeys. To exceed this limit required special waivers. The relaxation of this restriction effectively allowed timber frame buildings to be built up to eight storeys without any additional fire resistance requirements other than those existing for three storey constructions, however, no comprehensive design rules existed for timber frame buildings over four storeys so the Building Research Establishment (BRE) and TRADA carried out a joint feasibility study with the objective of providing the necessary technical tools for the safe and economic construction of medium rise timber frame buildings in the UK.

Fire Resistance

The fire resistance test carried out within one of the apartments of the TF 2000 building demonstrated that timber frame construction can meet the functional requirements of the Building Regulations for England and Wales and the Building Standards for Scotland in terms of limiting internal fire spread and maintaining structural integrity.

In meeting the requirements of the regulations and the objectives of the research programme two conclusions were drawn:

- The standard of workmanship is of crucial importance in providing the necessary fire resistance performance especially in fixing of plasterboard.
- Correct location and installation of cavity barriers and firestops is important in maintaining the integrity of the structure.

Fire Resistance of Timber Stairwell

The TF 2000 research investigated the performance of timber stairs within a timber frame apartment block. According to guidance in Approved Document B (Fire Safety) of the England and Wales Building Regulations, a single stair serving a building of the height of the TF 2000 building should be constructed from materials of limited combustibility. Timber does not fall into this category.
The time saved on site erecting a timber frame can be lost if critical elements of the building cannot be completed at a similar speed; the use of cast concrete stairs is one example where time can be lost. In meeting the Building Regulations, the fundamental consideration for a stair is:

‘The stair has to remain useable for fire fighting after initial evacuation of occupants immediately at risk and for subsequent evacuation by the other occupants of the flats who are initially advised to remain in their dwellings.’

Full-scale fire tests were carried out using standard white wood timber stairs impregnated with a fire protected timber treatment and using thermosetting glue. The tests demonstrated that the specific timber type and treatment used for the experiment together provided an appropriate level of fire performance to satisfy the functional fire safety objectives for a stair in the residential building. In contrast the Scottish Technical Standards require that the enclosure of the stair and lobby be of noncombustible construction and the stairs, landing and lobby floors also be of non-combustible construction. This rules out the use of timber frame construction in these areas of otherwise TF buildings constructed in Scotland.

**Differential Movement**
Differential movement between the timber frame and the brickwork cladding of the experimental building was an important design detail consideration as the amount of movement increased with respect to the number of storeys. Shrinkage of timber mostly occurs across the grain, therefore three methods may be used to minimise timber shrinkage.

- Minimise the amount of cross-grained timber within each storey, i.e. floors should be supported off floor panels as opposed to being laid across them.
- The specification and use of super dried joists at a moisture content of about 12%.
- The use of engineered wood products such as ‘I’ beams, etc.

Overall the use of super dried joists in combination with brickwork cladding of a low moisture movement was shown to result in a design value of less than 30 mm movement over six storeys.

**Disproportionate Collapse**
The UK Building Regulations (Scotland, Northern Ireland, England and Wales) all require that buildings above four storeys must be robust and able to resist disproportionate collapse. The programme concluded that with good design a six storey timber frame building satisfied the Building Regulations in terms of resisting disproportionate collapse.
Commercial Findings

The UK construction market has come under increasing pressure to maximise limited land resources and to increase population densities and the market for medium rise developments is growing. The TF 2000 project indicated that considerable savings can be gained from off or on site prefabrication combined with the use of trained erection teams, making medium rise timber frame an attractive building solution. Notwithstanding the above, there are a number of points which may act as barriers to the greater acceptance of five and six storey timber frame buildings in the UK construction industry:

- Knowledge. The majority of designers, architects, engineers and contractors are not aware of the full capabilities and advantages that timber frame can offer.
- Current Building Regulations in Scotland limit timber frame buildings to a maximum of 11 m or five storeys. This is because of the non-combustibility clauses, especially for protected shafts.
- The requirement for specific design provisions such as those for resisting disproportionate collapse adds significant costs and can reduce the contractor's profit margin to the point where extra storeys are no longer economic.

A4.1 Case Study: The Reflection Building, North Woolwich, London, UK

The Decision to Build Timber Frame

St. James Homes purchased a plot of vacant building land on the North bank of the River Thames in north woolwich, London. Site conditions for a six storey development comprising 21 one and two bedroom apartments were discovered to be more difficult than first thought. During the construction of the Thames Flood Barrier (opened in 1984), the land was surrounded on two sides by sheet piled concrete flood defence walls. Ground anchors supporting the walls were tied back into the site, which meant that to avoid damage to the anchors, traditional piling techniques could not be used on the new building.

To overcome the problems of ground anchors, a high water table and the presence of peat and contamination on site, a reinforced concrete buoyancy raft foundation was designed. To reduce ground water, voids in the honeycomb structure were to be filled with polystyrene. The soil to be removed was calculated to equal the weight of the foundations and superstructure that would replace it. To keep the superstructure weight within practical levels, a timber frame was suggested by the structural engineers as a lightweight solution.

Tully De’Ath Associates were appointed structural engineers for the whole project. Chiltern Clarkebond was brought on board as specialist timber frame structural engineers by Bedford and
Jennings who submitted the successful tender for the timber frame design, manufacture and construction.

With the outline plans and particulars drawn up, St. James Homes needed a timber frame design that maintained the agreed overall dimensions. The building was to have six timber frame storeys, wall staggers, floor steps, and five different roof areas - the design was challenging in all aspects.

**Design Issues**
The six storey timber frame was designed to sit on a single storey reinforced concrete slab. To bring the building within the required 18 m height for 60-minute fire resistance but still achieve 6 storeys, floor zone depth was critical. Joist spans were limited by the fact that no more than a 241 mm joist could be used. Because joists could not span between external walls, a complicated joist layout plan was needed making many internal walls load bearing. To keep differential movement as low as possible, horizontal cross grain timber was kept to a minimum. ‘I’ beam joists were chosen as a manufactured product giving reduced and predictable shrinkage in the floor zone that fitted the required floor zone dimensions.

**Disproportionate Collapse**
Disproportionate collapse columns and beams formed a skeleton around and through the building structure. Steel connection plates joined all node points. If a wall panel were removed, the building would not collapse, as the load would be redistributed through the disproportionate collapse columns and beams. At the time of design, the concern about disproportionate collapse meant that many more posts were specified than were necessary. As information from the TF 2000 project was analysed and compared, posts were removed by the design team where they were not needed.

**Racking Resistance**
In the six storey Reflection building, walls were sheathed with 9 mm OSB which provided the necessary racking resistance while being as thin as practicable to keep weight to a minimum. Because of the size, height and exposed site conditions, many walls were sheathed with OSB.

The Reflection structure was designed so that all necessary racking resistance was provided by the timber frame. No temporary cross bracing was required during the construction and the installation of plasterboard provided racking resistance in addition to that which was necessary. The designers were concerned that, due to the height and size of the project, the building risked damage if full racking resistance could only be achieved when all walls were dry lined. This was the driver for using OSB sheathing on the internal walls.
Wind Loads
Due to its location five metres above sea level on the banks of the Thames Estuary, the Reflection site is exposed to a considerable wind load. Before windows were installed into the wall panels, wind gust had the potential to cause damage to the building from within. In addition, the building height topped with wing shaped roofs added potential wind uplift. Chiltern Clarkebond delivered a comprehensive fixing schedule, specifying many fixings to ensure that the building performed as intended during construction.

Fire
60-minute fire resistance was required in the Reflection Building.

Acoustics
The Reflection Building used timber frame party walls held together with party wall straps located at each storey height. Insulation was placed in one leaf of the party wall, which, with the cavity and plasterboard, combined to provide adequate acoustic properties. Party wall straps provide a structural connection across the void of party walls and can therefore reduce the acoustic performance of the wall so their numbers were kept to a minimum.

Timber floor decks with a separate floor that floated on dense mineral wool insulation prevented floor impact sound travelling through the walls and floors.

Timber Stairs
The time saved on site erecting a timber frame can be lost if critical elements of the building cannot be completed at a similar speed. The use of cast concrete stairs is one example where time can be lost. The information gained at TF 2000 allowed St. James Homes to use timber stairs in the Reflection project.

Manufacture
The materials used in the panels were typical of panel manufacture in the UK. 38 mm x 89 mm C16 grade studs were cut and fixed in the factory using OSB sheathing and breather membrane. Floor to structural ceiling height exceeded the height of a standard panel, so OSB panels were manufactured as a special order. This removed the need to cut a second board to achieve wall panel height and removed the need for noggins to support the board edges at 2.4 metres height. Noggins were still required to support edges of plasterboard at 2.4 metres to comply with fire regulations.
Two main differences in the construction of the wall panels were that 9 mm OSB was nailed to the frame at close fixing centres of 50 mm increasing to 150 mm at the upper level. Lower storey wall panels had many multiple stud clusters carrying load from upper levels.

Due to storage constraints both at the manufacturing unit and on site, panels were manufactured in order of use. A spray painted colour-coded system was used to identify panels belonging to the same flat. The manufacturing facility was kept informed of the speed of erection on site to ensure that made-up wall panels were not stored for long periods but were available when needed.

Manufactured timber joists and floor deck material were delivered directly to site and stored outside, raised off the ground and covered with polythene. Problems arose when it was found that packs of joists were not for individual flats but clustered together with similar sized beams. Extracting the required beams for the current working area from several large packs proved time-consuming and had the potential to cause damage to the beams from double handling and the need to remove the supplier’s weather protection around the packs.

**Erection of Frame**

Sole plates were laid on the first floor concrete slab, which was reasonably level in most areas. High spots along one edge of the slab were ground down to reduce the need for structural shims in other areas. The sole plate fitted the slab well except in one area where a miscalculation during the slab construction had led to a considerable slab overhang. As the frame erection work progressed, staff from TRADA Technology frameCHECK\(^9\) began regular site visits twice a week to monitor all aspects of the timber frame.

Because of the exposed site location and building height, close spacing of fixings were essential to hold the building together. Fixing types and centres were recorded in a comprehensive fixing specification. The erection crew did not immediately recognise that the fixing schedule was much different from what they were used to. Sole plates to slab fixings were not installed to the structural engineer’s specification and following a frameCHECK\(^9\) site visit, the erectors had to re-check their work and install the missing fixings into the sole plate. In areas where walls were quickly erected on sole plates, an additional detail using a metal strap shot fired to the slab and sole plate edge was used.

Wall panels to the lower floors of the building had many clusters of cripple studs transferring vertical load.
The building was erected floor by floor across the site. This method allowed all floors to be kept level and was the most efficient method for the erectors. Another method that could have been considered would have been to construct the six storey section first. Once the roof was on, this area of the building could begin service installation, flooring and dry lining while the frame erectors worked on the other areas.

Floor cassettes were not used in the Reflection project. ‘I’ beam joists were fixed to rim beams using joist hangers. The time taken to fix hangers and joists proved to take much longer than anticipated. This slowed the construction process and had a major cost implication for the erectors. Another reason for delays in the erection process was insufficient labour to the site. A core of three individual erectors put up most of the timber frame. Because of the large building area and the time-consuming floor systems, the site could have kept five teams of three individuals busy.

Many problems identified in frameCHECK reports were not rectified until all of the building was erected. Available labour was concentrated on continued erection until the building was complete. This led to additional cost in identifying, fixing and re-checking work.

Service Installations
St. James Homes limited the risk of expensive and difficult to repair damage caused by tradesmen without the appropriate training for timber services installation by using suspended ceilings to allow services to run between joists and finished ceilings without compromising the structure of joists and disproportionate collapse beams.

The choice of electricity for heating water and space heating may have been an economic issue and not specifically chosen for timber frame. The routing of cables instead of pipe work allowed smaller holes and fewer service routes to be cut out, thus limiting any potential damage to the timber frame.

The route for extractor fan ducts from internal bathrooms to an outside wall was input at the design stage, running parallel to floor joists. The design incorporated how it exited the floor zone through the external wall, with consideration for structural elements and differential movement.

The lift shafts were constructed using timber frame party wall detailing with additional party wall straps located in floor zones for stability to avoid the inclusion of a ‘wet’ trade and the use of different materials such as concrete block in the lift shafts, which can reduce the speed and efficiency of construction. Lifts can be programmed to stop level with floors and self adjust for minor changes to accommodate differential movement or shrinkage of the timber frame.
Cladding
Brickwork can be successfully used with timber frame buildings without reducing construction time because the work can be removed from the critical path but it is a slow method of cladding, is built off its own foundations and adds substantially to the weight of the building. Due to the poor ground conditions on the Reflection site with the whole building effectively floating on a raft foundation, a lightweight rendered cladding system was chosen to keep weight to an acceptable level with a cavity between the cladding and the breather membrane to prevent conditions capable of causing decay in the timber.

The cavity was formed using treated timber battens screwed into the timber frame studs. A stainless steel mesh was fixed to the timber studs and a proprietary render system applied. The regular expansion gaps required in most render systems were not required with this system as the render material was designed to be flexible and capable of absorbing differential movement. Unusually, ventilation and drainage is provided at the base of the cladding only. The render system is designed to be breathable.

Lessons Learnt, Problems Identified, Workmanship
- Timber frame is thought to be more expensive to use than brick and block. One question raised was the availability of timber frame labour; would an increase in demand push up prices and lower quality? St. James home were prepared to use timber frame due to speed of construction and cash flow.
- One major concern of timber frame seems to be floor construction. Acoustic failures are thought to be due to poor installation. Training and education of installers should be undertaken, explaining why certain ways of doing things are crucial to the whole building performance. Concern has been expressed about the acoustic performance of floors in the building if occupiers choose hard floor finishes instead of carpets.
- By choosing one material, you are often channelled into using another. For example, TJI joists lead you to using Simpson Strongtie joist hangers because they are made to fit precisely together and are provided with structural calculations.
- Floor cassettes can save time on site. The Reflection project used hundreds of joist hangers each held in place with many nails. The time taken to assemble each floor on site was considerable.
- Location of bathrooms and extractor fan routes can add greatly to costs. Suspended ceilings for services can ease on-site problems.
- Timber lifts and stairs were installed, again to keep building weight to a minimum. St. James could only find one lift company who would erect an independently supported steel frame cage.
in the lift shaft for the lift to run in. Timber lift shafts and stairs have enhanced detailing and site problems with regard to acoustics and fire.

- Disproportionate collapse requirements did not, in the end, have such a large impact on the building. Further testing of the requirements for disproportionate collapse may in the future lead to further reductions.
- The timber frame manufacturer and specialist engineer should have been involved in the project earlier.

Next Time - Solutions and Innovations

- The initial design did not consider timber frame as a construction solution. Changes in levels of floors, wall staggering, roof detailing and beam spans and floor zone depths posed problems for the timber frame designers as they were working to the constraints of an existing plan. Involvement of the timber frame designer at an earlier stage could have minimised many of the design problems encountered by the frame manufacturer.
- Prior to construction on site, educating the erection team as to the peculiarities of multi storey timber frame should be considered.
- Scaffolding – do we need it? North America constructs timber frame buildings without scaffold. In the UK, we erect a scaffold for timber frame erection and then change the lift heights for cladding. Can a better system be used or can a building be erected on the inside using erectors on lifelines?
- Scaffolding on the project caused several delays on the critical path to construction. The scaffold lifts needed to be altered from one height to suit the timber frame erection to another height for the rendering. Tying in of the scaffold needs to be considered.
- Consider using 140 mm studs in particular at lower elevations instead of many 89 mm stud clusters or studs at close centres.
- More visits to site would have allowed structural engineers to learn more and solve problems easier. Because of the issue of liability, not enough site visits were made.
- Structural engineers need knowledge of acoustic and fire issues to allow them to take account of requirements in their design.
- Additional tolerances are needed around timber lift shafts and stairways, an extra 50 mm has been suggested.
- To speed up design and tender process, at the beginning, the design should concentrate only on planning drawings and information required to tender. An alternative is early partnership and planning. A better price can be achieved by determining an accurate plan area, direction of joist spans and joist material. The key seems to be to employ an architect who understands timber frame.
Top hung pressed web beams could have speeded the contract time up by 4 weeks.

The ‘I’ beam joists required many hangers, all nailed to rim beams. Could floor cassettes, top hung beams or joists bearing directly onto top rail of wall panels have been used?

Overall design comments for future projects: designing cross sections and sole plates right, early, saves construction costs. Using closer nailing centres could reduce OSB sheathing thickness.

Panel sizes are determined by lengths of supplied timber, the ability to lift panels in the factory and on site, lorry size and available crane time. Large panels requiring craning cannot be erected in strong winds or if a crane is not available. A mix of large and small panels may allow work to continue when the crane is out of action.

The degree of panel finishing was assessed. Windows could be installed into panels at the factory. However, panels would then need to be transported and handled in a less efficient manner and damage or breakage would occur. Fitting of windows on site appears to be a quick operation. As long as the windows can be fitted on site without holding up the programme, there seems to be no time or quality advantage to factory fitting. Factory fitted windows, however, do allow for a wind and waterproof wall to be installed, reducing moisture content of timber and damage to building components.