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BIM: Marching to Level 3 – Can the Law Keep Pace?

By Frank Newbery

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Most construction industry managers and professionals will be aware that, since April of this year, all projects procured by the UK government must conform to BIM Level 2 methods for building information modelling and management.

At BIM L2 different designers are expected to produce computer models of their particular input which, whilst distinct in origin, are capable of electronic "federation" within a Common Data Environment. This federated model is intended to produce a comprehensive and thoroughly resolved depiction and definition of the entire building, including comprehensive data on all of its elements arranged in a structured and retrievable form.

On balance the industry's response has been positive, with growing recognition and adoption of BIM L2 technologies and organisational methods. Adopters encounter BIM's inherent need for closer and more extensive collaboration between contributing parties, often including specialist subcontractors and suppliers as well as the usual design professionals.

This increased degree of collaboration has in turn given rise to concern whether existing forms of building and professional appointment contracts can adequately separate, define and safeguard the interests of different BIM contributors.

In anticipation of this year's BIM L2 requirement, the Construction Industry Council published in 2013 its CIC BIM Protocol together with ancillary documents and guides. The Protocol functions as an annexe to common existing bilateral construction contracts or professional deeds of appointment, having the effect of binding them all together and adapting them to BIM L2 methods and inter-party relationships.

Today in 2016 the CIC BIM Protocol appears to have survived as the current UK "industry standard" for its purpose, although many major contractors and client bodies have preferred to develop their own forms of BIM-accommodation from documents and procedures already familiar to them. The current CIC BIM Protocol, particularly with its guidance for PI insurance, explicitly limits its own scope to Level 2 BIM implementation, i.e. with the contributions of the participants fully distinguishable and separable from a "federated" BIM model.

BIM capabilities and aspirations continue however to move forward. In February 2015 the Government published *Digital Built Britain – Level 3 Building Information Modelling – Strategic Plan* ("DBB") [1]. DBB envisages that by 2025 the UK construction industry should attain (inter alia): new international 'Open Data' standards, new collaborative contractual frameworks and a co-operative cultural environment.

The Government has more recently reinforced this commitment to BIM L3 by allocating £15M for this purpose in the March 2016 budget. Building on initiatives already taken by the government's "BIM Task Group", a quasi-official "UK BIM Alliance" ("UKBA") is to be launched this year. Its first aim will be to establish BIM L2 as *"business as usual"*, then to promote advancement to BIM L3 according to a *"staged plan with mandated milestones"*. It is not yet clear what effect the June 2016 referendum and its fallout will have on these initiatives, but the development and export of BIM construction capability could be seen as advantageous to the UK in any future global context.

The technology of BIM has meanwhile been evolving somewhat patchily, pulled between the opposing impulses of all-benefitting standardisation and market-capturing innovation. Difficulty still persists in defining standards or consensual norms for e.g: BIM object data classification and content; Levels of Definition/Detail. BIM software appears to be advancing most prominently into the sphere of information management, with emphasis on easy integration and retrieval of elements from diverse sources, sophisticated clash-checking, portability and general user-friendliness.

These motivating and enabling trends have not so far been matched by corresponding developments in Law.

King's College has recently published a paper [2] which suggests that the current CIC BIM Protocol has provided a good starting point, but could now benefit from updating so as to impose less onus upon Employers, toughen the obligations of project team members and allow more flexible multilateral relations between BIM project participants.

Some legal commentators take the view that even BIM L2 has hardly yet been digested, and that BIM L3 with its necessarily much higher degree of collaboration will inevitably break the bounds of what most current common contracts can reasonably handle – to the point where, for instance, two-party contracts will become obsolete. If this does happen then parties' protection under new forms of contract will be vitally reliant upon preserving data authorship trails through evolving BIM models. Parallel concerns affect licensing/IP rights in an environment where separate creativities are blended.

Another trend associated with BIM's evolution is the increasing perception of building projects as providing not just a new building but a whole prescribed building life-cycle including facilities management, maintenance and eventual demolition. This ties in with the concept of "servitisation", whereby an Employer buys not just a building, but a reliably satisfactory environment for a useful period of time. From a legal perspective this generates a need for corresponding "handover plus extended aftermath" building contracts. It also raises a fundamental concern insofar as projects of this nature will inevitably tend to blur the distinction between the generally accepted professional standard of "reasonable skill and care" and the much more onerous standard of "fitness for purpose".

[1] Download at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/410096/bis-15-155-digital-built-britain-level-3-strategy.pdf

[2] ENABLING BIM THROUGH PROCUREMENT AND CONTRACTS (July 2016) by King's College Centre of Construction Law and Dispute Resolution, BIM research group chaired by Professor David Mosey. Downloadable from KCL website https://www.kcl.ac.uk/law/research/centres/construction/enabling-bim/ebimtpac-form.aspx.

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Procurement – A View From Dubai, Part 1

By Karen Pharaoh-Tillon

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Dubai stands as a premier business and tourist destination equipped to welcome more than 180 nations and an international audience in excess of 25 million visitors for Dubai Expo 2020.
It has been reported that about $86.2bn of construction contracts will have been awarded in 2016, with an expected $8.8bn of further investment in both real estate and construction being awarded over the coming two to three years in readiness for the forthcoming Expo. The timing and structure of these awards has been and will continue to remain uncertain, however. Also, competition is fierce as companies fight aggressively for work, to replace the gaps left by projects being handed over or lost at tender. This will require a fresh response to the new and upcoming challenges that will define its future.

Low bid prices, lengthy payment delays and poor cash flow and liquidity are amongst the biggest issues facing the construction industry in 2016. Owners and contractors therefore need to be reviewing their tendering processes to ensure they achieve the best results in this difficult commercial climate. The adoption of an explicit procurement strategy, defining priorities and targets and methods of achieving them, can be the key to avoiding, or at least mitigating, the difficulties and to *"winning that next tender"*.

What should such a strategy consist of? Having spent the past 27 years working within the construction industry for developers, consultants and contractors alike, both in the Middle East and in the UK, I have identified ten principles that represent best practice. If applied systematically for each and every tender, these principles should provide a good prospect of success. The first five are described below, the remainder will be covered in a later article.

1: Feedback

Obtaining feedback, irrespective of whether a previous project tender was won or lost, is the single most important principle. A surprising number of Tenderers do not ask for feedback on the completion of a tender and consequently risk making the same mistakes.

A few years ago, during the final stage of a very long tender evaluation process, a Post Tender Clarification meeting was arranged with the two "shortlisted" tenderers ('TA' and 'TB'). The aim was to clarify any misunderstandings and most importantly to meet the nominated Project Director and the proposed project teams.

Both tenderers were capable of undertaking the project and had put forward similarly priced commercially and technically compliant tenders. With little to differentiate the two, the outcome would therefore most likely depend on the Owner's evaluation of the proposed Project team. Unfortunately TA, although excellent on paper and initially appearing to be the favourite, presented a Team Director who although very confident in his abilities was ill prepared for the meeting and clashed heavily with the Client Director. TB on the other hand put forward a very charismatic Project Director, who not only presented himself with perfect diplomacy and confidence, but also knew the project inside and out. TB was awarded the Contract.

A few months later another tender opportunity arose and the same two contractors submitted bids. Following a thorough review and the completion of a Tender Evaluation Analysis TA was swiftly removed simply because it proposed the same project team, and project director, as their previous tender. A request for feedback after the first tender, if acted upon appropriately, would have avoided wasting the time and resources expended in the tender and provided a realistic chance of being selected.

2: Careful Selection

Competitive tendering is increasingly expensive. Deciding which tenders to compete for and which to avoid is, therefore, commercially critical. Clients will normally contact prospective tenderers and issue a formal Inquiry Package in addition to a standard Pre-Qualification Questionnaire (PQQ). At this point a commercially savvy contractor must consider;

1. Whether to choose quality over quantity;
2. Whether the opportunity fits the business and will involve local staff, thereby alleviating time and resource wastage;
3. Complexity of the project;
4. Controllable variations;
5. Price certainty and
6. Completion

Without exception, Clients prefer honesty. It is important, therefore not to take on more than can be delivered at the right level of quality. This applies bot to Tender stage and during construction. It is far better to decline to tender, but remain on the client approved lists, than to fail to tender or, worse still, submit a cover price, and be blacklisted.

3: Preparation

Preparation should be at the forefront of an organisation's mission statement. Five common reasons for failure are;

1. Incorrect cost schedules/BOQ in addition to an uncompetitive proposal;
2. Information/schedules missing (failure to collect Addendums) attributing to the lack of understanding of both the Client and Clients' brief;
3. Questions/RFIs – missed, unanswered or misunderstood, leading to incorrect assumptions;
4. Inappropriate/poor Project Team selection

All of these may be avoided with careful preparation. The popular adage, often attributed to Benjamin Franklin, *"Failing to plan is planning to fail"*, may seem trite, but often proves true.

To avoid repetitive failure, particularly in the Middle East, when submitting otherwise commercially compliant bids, it is vital that procurement departments plan ahead by collating the key tender information documents regularly requested for every tender, without which Tenders can/will be disqualified;

1. Insurance;
2. Trade License;
3. CV's;
4. Company Background and Organisation Charts;
5. Financials; and
6. Quality, H&S manuals

However tempting it might be, do not skip sections or leave any gaps. A tender with information either missing or *"to follow"* will not only prolong the process but also frustrate members of the Tender Committee. This is likely to result in a low score, if not zero, being assigned to this element. Exclusion of the Tenderer will normally follow.

Finally, don't assume that there will be a second chance when tendering or that your tender will not be reviewed thoroughly to ensure responsiveness to all commercial and technical provisions. Clients know most if not all the tricks and are only too aware of tenders submitted that have been rushed and left to the last minute. Don't take the risk. Tenderers will be excluded from further evaluation should they be non-compliant, contain too many contractual deviations or offer uncompetitive proposals.

4: Questions/RFI

Asking questions or requesting additional information during the tender period is not only essential but exceedingly useful and for many Tender Committee members an important part of the tendering procedure. Not only can Tenderers raise concerns perhaps relating to the omission or misapplication of an element of work, design, drawing, specification etc., but any ambiguity or misunderstanding of the design or pricing information contained within the tender documents can be removed and or made clear which will help the tender to move along more efficiently. In addition, the tender committee can ascertain very quickly which Tenderers are taking the project seriously and how keen they are on working on the project. Above all, where Tenderers are reviewing all the documents, it is likely that they will bring to the attention of the Tender Committee, any design or inferior material that may not meet the Client's needs or intended use.

The only proviso regarding questions is that the documents, and any addenda, must be thoroughly reviewed beforehand, to ensure that the questions are genuinely relevant, make sense and do not have the effect of wasting time or unduly prolonging the tender period.

If you are to ask only one question, ask for sight of the Tender Evaluation Matrix; the guide to how the tenders will be marked. This will be project specific and will show how the criteria for evaluation will be weighted according to the Client's needs. You can then concentrate the tender team's initial efforts on answering the high-scoring questions.

5: Relate

What Clients appreciate most of all is when Tenderers look beyond the stated requirements to put themselves in the Clients shoes, and successfully understand their paramount needs and requirements with respect to the project.

In particular, any accompanying documentation in terms of the experience of your organisation and the selected team should focus on how these relate to the Client's needs and requirements and how they can help provide appropriate, creative and ingenious solutions. The client already knows how good you are; your tender should demonstrate why you are right for the execution of this particular project.

Part 2 to follow...

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Fire Safety in Tall Buildings, Part 2 – The Future

By Martin Edwards

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Introduction

The taller the building, the longer it takes for the occupants to escape and the more difficult it becomes for firefighters to achieve a rapid intervention to prevent the fire spreading or to rescue the occupants. Evacuation time may approach or even exceed the period of fire resistance to the structure. What additional measures should be taken to maintain the safety of the occupants, neighbours and firefighters as building heights increase relentlessly? Are there fire safety innovations to match the bold advances of skyscraper design?

The ill-fated World Trade Center in New York City (WTC) has been studied more than any other tall building, because of the attacks in 1993 and 2001, the total evacuations that were attempted and the structural collapses. The fire safety systems in place at WTC were stretched to their limits and beyond. The National Institute of Standards and Technology (NIST) report of the incidents provides invaluable data for future fire safety design in supertall and megatall buildings [1].

Fire Break Floors

Compartmentation is increasingly important with rising height of the building. Ideally, the entire contents of a storey should be consumed without causing vertical fire spread or structural damage.

The fire break concept is a progression from normal compartmentation, with the intention that a non-catastrophic fire should not disrupt occupants remote from the fire. In addition to normal sprinkler coverage and compartmentation between floors, "fire break floors" provide enhanced horizontal separation between discrete parts of a tall building. Typically, this is provided by plant floors, which are unoccupied and have low fire load. The fire breaks and multiple plant rooms allow each sector of the building to operate almost independently, minimising the vertical connections between the different parts of the building, other than the fire resistant stair, lift and service shafts.

An example is the 306m Shard in London, which is subdivided by plant floors at 3 intermediate heights, separating the various functions of the mixed-use tower: public viewing galleries, private residential floors, hotel / restaurant and offices at the base. This has allowed the fire risk in each part of the building and a range of possible intensities and durations of fire, to be considered independently, resulting in appropriate structural fire engineering solutions being devised for each zone. Differing levels of passive fire protection were applied to the different structures in various parts of the building [2]. Similarly, the 632m Shanghai tower is designed as nine zones, "*cylindrical buildings stacked one atop another*". [3]

Evacuation

Much of the focus of tall building design concerns means of escape in the event of fire. Tall buildings place the occupant remote from the ground, up to 585m high in Dubai's Burj Khalifa. The occupants must therefore be provided with a place of safety from the effects of fire (the 'stay-put' strategy), or provided with efficient and rapid means descending the building to safety. Alternatively, some intermediate safe evacuation strategy ('phased evacuation') has to be devised to provide a reasonable standard of safety for all building occupants during a fire event.

Staircases have traditionally been the only means of escape from upper storeys after a fire alarm has sounded. Generations of skyscraper occupants have been drilled not to use the lifts in the event of fire. This has had to change as the enormous heights of skyscrapers make descent of hundreds of flights of stairs increasingly impractical. Ever since the loss of 2,749 civilian and firefighter lives in the 2001 WTC attack and fire, [4] there has been renewed interest in the use of lifts for the emergency evacuation of tall buildings.

Stairs and lifts take up a considerable proportion of the gross floor area of a skyscraper and their design is influenced by the commercial imperative to maximise usable floor area. Lifts tend to be clustered together in a central core in the heart of the floor plan, leaving the perimeter of the plan as usable area. In normal non-emergency use, a full-height lift stopping at all floors would be undesirable, both because of its slowness and because of security: the larger the building, the more likely it is to have multiple occupants. Therefore there tends to be a variety of lift stopping patterns: express lifts to the uppermost storeys, express lifts to transfer levels or "skylobbies", limited stop lifts by-passing intermediate storeys, and local all-floors distributor lifts.

A sky lobby is an intermediate floor where people can change from an express lift that only stops at the sky lobby to a local elevator which stops at every floor (or every alternate floor if double-deck lifts are included) within a segment of the building. Skylobbies were included in both WTC1 and WTC2 towers at floor levels 44 and 78.

When a local lift shaft terminates, the space it occupies on the floors above will be taken either by commercial floor space, or by another lift or a stair. Thus the floor plan varies up the height of the building. Staircases, in particular, may not be in the same location on every floor. Persons using the stairs for fire escape may find unfamiliar and disorientating layouts around skylobbies and on lower storeys.

Stairs

Every escape stair should be wide enough to accommodate the number of persons needing to use it in an emergency. The number of staircases to be provided, and their width, are determined from the number of storeys, the occupancy level, dimensions of the floor plan and other criteria, and are intended to ensure means of escape at all material times. Staircase width is also dependent on the fire escape strategy: either simultaneous or phased evacuation. Stairs for simultaneous evacuation allow for all occupants to leave the building together at the earliest opportunity, but require multiple broad staircases. Phased evacuation allows narrower stairs than necessary for simultaneous evacuation, increasing the usable floor area, so phased evacuation is the norm for non-residential and mixed use skyscrapers. The 'stay-put' or 'defend-in-place' strategy is often applied to residential buildings. This strategy relies heavily on effective compartmentation, containing the fire to the floor of origin until it burns itself out without structural collapse. All fire precautions are futile if the building collapses.

Phased evacuation is a strategy to allow the clearance of those most at risk first. The first people to be evacuated are those on the fire floor and the floor immediately above, including occupants with reduced mobility. This may be sufficient. The fire may be extinguished by sprinklers or by the fire service without need for evacuation of the whole building. If phased evacuation must continue, it is organised by a trained team to follow in a planned sequence, typically:

- 2nd and 3rd floors above the fire floor;
- 4th and 5th floors above the fire floor;
- Repeat upwards to the top level;
- 1st and 2nd floors below the fire floor; *

(* This may be brought forward by the fire service in order to establish a 'bridgehead', the operational base for firefighting, usually 2 storeys below fire floor or lowest affected floor.)

- Repeat downwards to the bottom level.

Occupants of low priority floors are instructed to stay put until it is their turn to evacuate. This message should be reinforced by bulletins on the progress of evacuation, so effective means of communication are important. Phased evacuation also relies on adequate compartmentation.

Stairs for phased evacuation are sized on the maximum storey occupancy, which may be determined by exceptionally high occupancies, for instance if there is a public access restaurant or observation gallery. Unless all the escape staircases are protected, either by a smoke control system or a protected lobby on every storey, it should be assumed that any one stair might not be available due to fire. The capacity of the remaining stair(s) should be adequate for the number of persons needing to escape.

The outcome of unorganised simultaneous evacuation may be judged by the events of the 1993 WTC bombing, the largest building evacuation ever recorded. The explosion cut off all power to the complex. As communication systems did not work, most of the building population made the decision to evacuate within a few minutes. Approximately 50,000 people evacuated from the WTC complex, including nearly 25,000 from each of the two towers, [5] without the use of lifts.

> *" Stairways were massively congested. Many occupants could not make the descent under their own power. Pregnant women, older people, people with heart conditions, and people with physical disabilities all required fire department assistance. Firefighters carried people down the stairs some 60 floors or more via stokes baskets* [metal framed stretchers]*, stair chairs, wheelchairs, and office chairs. Groups of children had to be escorted to street level — one group of children from the 92nd floor. Resuscitators and first aid were required for many occupants."* [1]

People from upper floors waited as long as an hour at pinch points while lower-floor occupants exited. Two of the three stairwells in each tower discharged into the smoke-filled mezzanine lobby, rather than directly to the exterior, slowing the evacuation. The evacuation of the towers took over 4 hours, [6] an average of 2¼ minutes / storey descent over the whole 110 storeys. By this time, ascending firefighters had reached the 80th floor [7] at approximately 3 minutes / storey. Movement speeds were significantly slower than mean speeds in published guidance based on measurements taken during fire drills, suggesting that the emergency evacuation speed was determined by the slowest occupants and those requiring assistance. [8]

Staircase evacuation times such as at WTC (1993) are likely to approach or exceed the period of fire protection to the building structure. UK guidance has a maximum fire resistance of 2 hours for the structural frame of buildings over 30m high.[9] In the UAE, where supertall towers abound, the maximum requirement is 4hrs fire resistance for buildings in excess of 128m high, reduced by one hour if there is full sprinkler coverage, [10] so the 828m Burj Khalifa is (probably) designed with 3hrs fire resistance to structure. The disparity of staircase evacuation time in emergency conditions and structural fire resistance is likely to increase with the increased heights of proposed new megatall skyscrapers.

In contrast to 1993, there were only approximately 17,400 people in the WTC towers at 08.46 on 11 September 2001 when the first attack took place: approximately 8,900 in WTC1 and 8,540 in WTC2. [11] In WTC1, where all 3 staircases were rendered unusable on and above the aircraft impact floors and power to lifts was cut off, there was an all-stair evacuation from floors 93 and below, which was to a large extent successful. 1355 people perished on and above the 5 impact floors, but a total of 7,450 or 98.6% of those below were successfully evacuated, and 6,700 or 88.8% of these survivors by 09.59 hrs, 72 mins after impact and 29 minutes before collapse.[12] There was water and debris in the stairwell and visibility was reduced by smoke and gypsum dust. However, the maximum rate of stair descent was faster than one minute per storey, considerably faster than in the congestion of 1993, but still slower than the slowest fire drill. [13]

NIST recorded that some mobility-impaired occupants in WTC were left by co-workers and they had to rely on strangers for assistance. Marring the general success of the lower storey evacuation, approximately 40-60 mobility-impaired occupants were left on the 12th floor of WTC1 in an attempt to clear stairways and many of these people were among the fatalities. [14]

Concurrent with the evacuation of WTC1, firefighters began to ascend the three stairways, counter to the general evacuation. Because the firefighters were carrying heavy equipment, progress was slow and the opposing evacuation movements impeded their ascent, presumably more in the 1.1m wide Stairwells A and C: Stairwell B was 1.4m wide. Nevertheless, some firefighters reached floors at levels 40s and 50s before WTC2 collapsed at 09:59 and they were all ordered out. The concussion and pressure pulse from the collapse raised more dust and smoke in the stairwells and the lights went out. The rate of evacuation halved. [15]

The general success of the evacuation below the 94th floor was very much a consequence of the low occupancy, due to the early hour, and both the first day of school year and a primary election falling on 11 September. Typical occupancy in 2001 would typically have been 20,000 in each tower. [16] NIST estimated that if the towers had been fully occupied, it would have taken 3 hours to evacuate the buildings. As WTC 1 collapsed after 1 hour 42 minutes and WTC 2 only 56 minutes after impact, 14,000 people might have perished [17] rather than the 2,400 building occupant victims on the day.

In WTC 2, occupants made the decision to evacuate after the attack on WTC1, and many of those on upper floors used the functioning lifts, so that approximately 3,200 people or 40% of the survivors exited in the 16 minutes before the second plane hit WTC2 at 09.03 hrs. [18] There were 619 fatalities on or above the 7 impact floors, less than half the victims in WTC 1, even though there were 24 occupied floors above impact levels rather than 10 occupied floors in WTC1. Although WTC2 collapsed only 72 minutes after the WTC1 attack, all but 11 of the remaining occupants below the impact floors escaped using the stairs before the building collapsed.

In addition, 18 people in WTC2 above the impact levels managed to negotiate the damaged Stairwell A and escape. [19] Unlike in WTC1, where the plane destroyed all 3 stairwells which were clustered closely together, in WTC 2 the stairs were widely separated and the plane damaged, but did not destroy, Stairwell A. [20] Wide separation of escape staircases may increase the robustness of evacuation provisions against a fire or other catastrophic event. Some more recent fire codes like NFPA 5000 (2003) require greater minimum separation of staircases than on the impact floors of WTC1. NIST found it conceivable that a 4th stairwell, depending on its location, could have remained passable allowing evacuation by additional occupants above the floors of impact. [21]

The narrower Stairwells A and C were sized for the phased evacuation of 120 people / storey and the wider Stairwell B for 150 people / storey, a total of 390 people / storey, almost identical to UK contemporary and present recommendations for phased evacuation. [22] The maximum occupancy was 365 / storey, so overall stair capacity was satisfactory for the offices. Stair capacity was reviewed by NYC Department of Buildings in 1995 and was apparently found to be adequate for the WTC1 restaurant and WTC2 observation deck on the 106th and 107th floors, each with over 1,000 design occupancy. However, post-disaster in 2005, the same department said a 4th exit stair was required for these public spaces. [23] NIST also considered it likely that a 4th stairway would have mitigated the insufficient egress capacity for full building evacuation of all 20,000 building occupants.

The rate of stair evacuation from WTC1 was slower than during fire drills because:

"- *Occupants encountered smoke and/or damage during evacuation.*
- *Occupants were unprepared for the physical challenge of full building evacuation.*
- *Occupants were not prepared to encounter transfer hallways during the descent.*
- *Mobility-impaired occupants were not universally identified or prepared for full building evacuation.*
- *Occupants interrupted their evacuation.*" [24]

WTC2 occupants reported that the obstacles to evacuation were:

crowded stairways;

lack of instructions and information; and injured or disabled evacuees in the stairwells. [25]

Counter-flows of ascending firefighters also slowed general evacuation. A significant proportion of occupants had a physical condition which impeded their ability to evacuate, including recent injury, chronic illness, recent surgery, obesity, heart condition, asthma, advanced age and pregnancy. [26]

Smokelogging in escape staircases is a common problem in fire conditions. A considerable proportion of evacuation time is spent in stairwells, so an environment free from smoke and heat is essential. The stairwell atmosphere may be maintained by pressurisation systems. However, one study has indicated that smoke entered the stairwell in a majority of tall building fires surveyed, whether the stairwells were pressurised or not. [27] Smoke and flames can rise up stairways above the fire floor, so evacuation strategy is normally to direct evacuees down to below the fire floor as soon as practicable. Smoke in the escape stair caused 6 deaths above the fire floor in the 2003 Cook County fire (USA), [28] when locked fire doors prevented the victims from leaving the staircase. [29] Sub-division of stairwells may not assist orientation, but diminishes the risk of smoke disabling an entire staircase over the full height of the building.

The UAE Civil Defence Code requires re-entry from escape stairs to the interior of the building every 5th storey and access from that storey to another exit, as in NFPA 101. [30] This was a response to the MGM Grand Hotel fire in 1980. Here, because of security considerations, doors were locked behind escaping occupants once they had entered stair enclosures. This prevented access to other floors when the stairways were filling with smoke, resulting in 84 fatalities. [31]

Fatigue is a factor in long stair descents, and demographics suggest it will be an increasing problem as people become older and heavier. For this reason, many of the latest skyscraper designs include "refuge floors" at about 15 / 20 / 25 storey intervals on the vertical descent: five in the 128 storey Shanghai Tower and eight in the 167 storey Jeddah Tower (Kingdom Tower) under construction in Saudi Arabia. Refuge floors are a requirement for tall buildings in some Asian and Middle Eastern countries and offer some respite at least in a long stair descent. Some of the refuge floors may also be skylobbies where evacuation lifts can be awaited. Sub-division of staircases in conjunction with this strategy reduces the risk of entire stair shafts filling with smoke. Refuge floors can also be employed to protect people with disabilities and/or injured evacuees, and can be used as a fire-fighting base and command point for rescue teams to assist evacuation. [32] [33] Leaving large floor areas empty is anathema to commercial developers and it may prove difficult for building owners / managers to resist the temptation to occupy the refuge floors. Exemptions from permissible development areas and business rates may be necessary to ensure refuge areas are provided initially and not abused subsequently.

"Skybridges" can link two or more skyscrapers to provide alternative escape routes. The 452m Petronas Towers in Kuala Lumpur include the most spectacular example of the "skybridge", in which the twin towers are linked by a double-deck bridge 58m long at levels 41 and 42, 170m in the air. [34] This effectively halves the vertical distance to be travelled using the staircases, because at the skybridge the occupants of the upper part of a fire-affected tower could traverse to the unaffected tower and exit using the lifts in the skylobby.

However, an emergency evacuation of the Petronas Towers after a bomb scare on the day after the WTC attack resulted in heavy congestion. Due to lack of information about the bomb's location, occupants of both towers attempted to cross the skybridge in opposite directions. Subsequent evacuation planning reduced the evacuation time to just 32 minutes in a 2002 fire drill. [35]

Ambulatory, mobility-impaired occupants descend slowly, often accompanied by a helper or helpers, blocking and delaying the descent of those following. Evacuation assist devices are available: stretchers, carry chairs, evacuation chairs and rescue sheets. Trials in Belgium demonstrated that the wheeled evacuation chair was fastest, required only a single handler, and being narrow, was the easiest to be overtaken by the able-bodied. [36]

Lifts

Prior to 1992, the advice in the UK was that passenger lifts should not be used for escape from fire except in very special circumstances (not specified): " *… Experience in fires has shown that misuse or malfunctioning of lifts has caused a number of deaths, attributed among other things to failure of the power supply or from lifts being called to or held at the fire floor. Once the car and landing doors are open their design is normally such that they remain open, exposing the occupants to fire.*" [37]

In the 1993 World Trade Center bombing, the explosion took out all power, but not before a large number of occupants had entered the lifts, where they were trapped. Firefighters had to locate and search all 99 elevator cars in each tower in order to rescue the occupants.

In 2001, the WTC1 impact disabled all lift service to the upper 60 floors. Half an hour after impact, only one of the upward elevators was working, which extended to the 16th floor only. In contrast, in WTC2 approximately 2,263 people (40% of the survivors) evacuated from the 77th floor or above in the 16 minutes before the plane strike, with a significant proportion using the lifts. The plane destroyed all elevator service to the impact floors. [38] 15 minutes after impact there was a single elevator operating up to the 40th floor. Using this lift and then the stairs, firefighters reached the 78th storey, the lowest impact-damaged floor, before the collapse. [39]

The functioning lifts greatly improved the survival prospects of WTC2 occupants high in the building and enabled the firefighters to reach the lowest fire floor. The WTC2 experience demonstrates the potential value of both evacuation lifts and firefighting lifts. These lifts can continue to function in fire conditions, provided that they are both fire protected and structurally hardened, with maintained power supply (possibly from duplicated and diversified motor rooms) and communications services.

The problems involved in evacuating a highly populated skyscraper, epitomised by the WTC experiences, has led to the increasing adoption of lifts for emergency evacuation. Evacuation lifts are of paramount importance for mobility-impaired occupants and could well have saved the unfortunate victims on the 12th floor of WTC1. Evacuation lifts specifically for the emergency evacuation of disabled persons have been accepted in the UK since 1992.

On the negative side, the use of lifts in fire conditions can lead to smoke spread via the lift shafts. Lift shafts are not pressure-sealed environments and most lift doors have no smoke seals. Smoke from the fire floor can be drawn into the shaft by negative pressure behind the lift car and expelled on previously unaffected floors when the lift direction of travel is reversed: the "piston effect".

Studies since the 1990s have concluded that the combined use of evacuation lifts and staircases in tall buildings reduces overall egress times substantially in comparison with stair-only evacuation. [40] Evacuation modelling results suggest that the most efficient and fastest evacuation strategy using lifts involves multiple skylobbies in conjunction with the use of staircases for initial descent, thus spreading the arrival of evacuees in the lift lobbies, and decreasing congestion and waiting times. In this way, a reduction in overall vertical evacuation time of 33% may be achieved. [41]

Tall and supertall buildings with high occupancy, such as office towers, benefit substantially from the use of evacuation lifts. Lower and less densely populated buildings gain less. For an office or hotel building up to 12 storeys high, there is no advantage in evacuation time from the use of lifts. [42]

The use of evacuation lifts is unlikely to reduce the requirements for stair provision, as stairs are still the principal means of evacuation. However, evacuation lifts can increase simultaneous evacuation capacity, as stairs are sized for phased evacuation in most tall buildings. Evacuation lifts can also improve the robustness of the means of escape, by increasing diversity and redundancy among the vertical escape options. [43] Evacuees can make an informed choice of the lift / stair alternatives if at least one of the staircases is located in proximity to the lifts.

Alternative Means of Escape

Other technical fixes for means of escape have been suggested: helicopter rescue, external ladders;

chutes ('aircraft' type and others); external descent lifts; zip wire escape pods (NASA style). None is accepted by UK Building Regulations and none is as technically developed as evacuation lifts.

Helipads are provided on flat roofs of many high buildings and routinely used by executives for access in congested cities such as Los Angeles and Sao Paulo. These include at least five supertall 300m skyscrapers, in Guangzhou, China; one topped by a helipad at 438m. [44] Helipads are exemplified by the Burj Al Arab, Dubai, where elite hotel guests arrive on a cantilevered pad hovering 210m over the waters of the Gulf. Why not evacuate by helicopter also?

Rooftop evacuation by helicopter has been carried out in emergencies, but cannot be relied upon. Landing on a tall building in fire conditions is always dangerous, because of smoke obscuration, air turbulence, updraughts caused by smoke and heat, and the presence of aerials, antennas and spires. [45] [46] In addition, escaping smoke and flames tend to cling to the exterior of the building (the 'Coanda effect') making rooftop conditions untenable. A helipad originally designed at level 157 of Jeddah's kilometre-high Kingdom Tower was considered to be unsuitable by helicopter pilots and will now become a private sky terrace. [47]

Helicopter rescue was carried out at WTC in 1993, when 28 people with medical difficulties were removed from the roof of the north tower. [48] The WTC 2001 collapse investigation report stated that helicopters could not have landed due to the severe heat and smoke. [49]

Helicopter evacuation would involve upward evacuation via the staircases in which mobility and fatigue would be major factors, far greater than in downward evacuation. In any event, typically each helicopter could carry only 8 or 10 people, so helicopter rescue will never be adequate for the mass evacuation of a high occupation skyscraper.

Firefighting from above is also considered to be of limited benefit, as water has to be delivered to the base of a fire, which is best achieved by sprinkler or similar suppression before firefighters arrive. [50] Los Angeles has now relaxed the 1958 LAFD "Requirement No. 10" which ensured its firefighting helicopters had access to some of the city's biggest skyscrapers. The compensatory measures include stairways, elevators, automatic sprinkler systems and video cameras that ensure safety, access and escape routes for firefighters and building occupants during emergencies. [51]

Human Behaviour

A spontaneous decision to evacuate immediately occurred after the WTC explosion and has been observed in many fire incidents. Occupants may discard 'stay-put' or phased evacuation strategies and head straight for the exit, causing congestion on the escape routes and increasing evacuation time. Lack of information and guidance was a factor at WTC (1993). Occupants' fear of remaining in a hostile environment may also jeopardise the refuge floor concept. [52]

The time to initiate evacuation in WTC1 (2001) was 3 – 5 minutes, higher near the plane impact floors. Damage to communication systems prevented announcements to evacuate. [53] In contrast, over 90% of occupants of WTC2 began to evacuate before the 2nd plane struck and three-quarters of occupants from above the lowest impact floor 78 had descended below the impact zone before the attack, [54] principally by using the lifts.

The 20th century advice not to use lifts for escape still prevails. In a relatively recent public survey, 66% of respondents refused to consider using a lift to evacuate. [55] However, occupants are increasingly likely to use lifts for evacuation with increasing floor height. Waiting tolerance increases correspondingly, but almost no occupants are willing to wait in a lift lobby for more than 10 [56] or 15 minutes. [57] Readiness to use lifts is also dependant on the crowd density encountered in lift lobbies and proximity of the staircase alternative. Willingness to wait for a lift is likely to depend on factors such as the perceived threat, knowledge of the lift system, information about progress of evacuation and waiting time, presence of authority figures and confidence in those persons. [58]

Information / Wayfinding

There were a number of issues which hampered the 2001 WTC evacuation including wayfinding. Many occupants did not know where the emergency stairs were located, as they habitually used the lifts. The WTC designs also incorporated two transfer corridors between the narrower escape staircases, above and below each of the skylobbies, at floors 42 and 48, and floors 76 and 82, connected by short staircases. The transfer corridors took the escape route around the lift shafts and mechanical equipment rooms. Despite fire drills, escaping occupants were not prepared to encounter these transfer corridors. The predicted evacuation times, had the buildings been fully occupied, would have exceeded 2 hours, according to Galea, [59] or 3 hours according to NIST, and therefore would have still been in progress at the times of collapse.

WTC1 survivors told of being unable to find the storey exits initially, and having to search for the continuation of the descent having reached the 44th floor skylobby. UK-based research showed that only 38% of people notice conventional exit signage in simulated emergencies, even with unobstructed line of sight, but that flashing arrows on the "running man" fire exit sign doubled the rate of detection. Another possible enhancement of 'dynamic signage' superimposes a flashing red cross over the fire exit sign to indicate a blocked or unsafe exit route. It is conceivable that in future intelligent evacuation systems could identify the optimal escape route and direct the evacuee towards it. [61]

Signs and messages should be clear and simple, easy to comprehend in an emergency situation. For this reason, the efficacy of the flashing red cross to negate a fire exit sign may be doubtful, as it sends mixed messages. Firefighters need to have clear confirmation of where they are in a building. The firefighting at the fatal Shirley Heights fire in Southampton (2013) was repeatedly hindered because the fire flat no. 72 had its entrance on the 9th floor, but arriving firefighters quite naturally assumed it was on the 7th floor. The ingenious scissor-stair flat layout was also difficult to comprehend.

In order to inform occupants' decision-making, real-time information about the evacuation and the elevator waiting time should be provided for people waiting in the lift lobbies. Studies in 2012 highlighted the importance of a correct messaging strategy, but revealed there were no standard requirements or widely recognised guidance for the messages about the use of emergency elevators, either for building occupants or for firefighters. [61]

The future design of supertall and megatall buildings is likely to include a mixture of the enhanced fire safety measures described above. Improved vertical separation can be achieved by sterile fire break floors and dispersed services which minimise vertical connections to the fire-hardened shafts. Lift shafts are likely to be subdivided, overlapping only at sky lobbies. The stair shafts are also likely to be subdivided several times in the height of the skyscraper, at refuge floors as well as the sky lobbies, which will isolate smoke hazards within discrete stair flights.

Escape staircases are required adjacent to lift lobbies, but also widely dispersed over the building plan to avoid a single fire incident disabling multiple staircases. The opportunity to escape from staircases back into normally occupied areas should also be available in fire conditions. The stair layouts may become complicated, so clear, readily comprehensible signage is essential. Intelligent signage may be able to direct the occupants to least-used stairs and lifts, and divert evacuees around danger zones during their descent.

Evacuation chairs can help the disabled in the initial stair descent, with minimal effect on descent speeds of able-bodied evacuees. Refuge floors can offer respite for old, infirm and injured occupants and a safe waiting place for lift evacuation. Evacuation lifts can be provided for the most vulnerable occupants while others use the staircases, reducing overall evacuation time significantly. There is no magic bullet, no single technical fix, to fire safety in these incredibly high buildings, but incremental improvements should make the megatall skyscraper as safe in fire conditions as any other building.

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