Human movement and safety: New approaches to facilities design

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Building developers, architects, and facilities managers need to have premises that are safe and can be profitably operated, but which are also exciting and create positive experiences for their users. This paper illustrates some innovations in the field of human movement and safety that have contributed to the success of recent projects. Four projects – the Beijing Olympics Water Cube, HSBC’s London headquarters, King’s Cross St Pancras Underground station in London, and the tunnel option for the Fehmarnbelt Fixed Link between Germany and Denmark – are briefly outlined.

Introduction
An existing regulatory environment can be the greatest impediment to optimising a design, but sometimes, as with the Water Cube, it is possible to use quantitative design to break free of these restrictions and get a much better result. The challenge of evacuating people from HSBC’s 44-storey London HQ shows how facilities management was helped to adapt procedures in an existing building, in a radical way, to new concerns about terrorism. At King’s Cross St Pancras, a modelling tool revealed an unexpected though beneficial interaction between human movement and the design of a circulation route, which changed long-held views on flow rates and space allowances. For the Fehmarnbelt Fixed Link, comparison of traditional hand calculation and computational analysis results gave hitherto unforeseen insight into the behaviours of high densities of people escaping from a possible tunnel accident.

These projects are exciting – through the creation of visual spaces that would not have been possible under traditional prescriptive design; safe – through ensuring escape capacity is fully utilised, which frequently has not happened under traditional design practice; and cost-efficient – through optimal use of existing building human movement capacity.

The importance of human movement and safety
Traditionally, human movement in buildings has been of concern only in the context of regulations for escape from fire, and that is still often the main driver. This regulatory (ie safety) context has expanded to include crowd safety in larger assembly buildings. Commercially, however, operators in the retail sector have developed considerable expertise in other, non-safety, aspects of movement that have been shown to increase revenue, and now find a use in transport hubs and elsewhere.
In the past, building design for human movement often focused on what occupants are expected to do in buildings, not on what they actually do. The approach tended to be conservative and inefficient, and was not necessarily a good way to deal with all the novel circumstances found in new projects. In other words, the old requirements could be solutions to a different problem from the one actually presented.

The need to focus on what occupants actually do raises several challenges for developers, architects, and facility managers. Quantifying how people really behave rather than relying on codes enables the critical benefits to be realised for facility managers, owners and operators, as shown in the case studies.

**Developments in human movement and safety research**

Buildings are increasing in size and becoming more complex, as are user requirements and customer expectations. Data relied on in the past is decreasing in its applicability. Fruin’s observations, for example, which led to industry-standard “levels of service” on population flows and density, are now dated. Pauls has recently withdrawn his widely-used data due to the population changes noted above.

Modern design codes and standards increasingly refer to evacuation strategies based on the time occupants may take to react and move, but generally can only offer simplistic guidance. For example, BS 9999 does not deal with building height and its implications for high-rise evacuations (other than to suggest that you might throw in an extra stair if the building is very tall).

Human movement researchers therefore have to address the new challenges of large, complex buildings occupied by an aging and less capable population with ever-higher expectations of service and comfort. It also has to be said that there is still much to be learnt, that could directly benefit design, about quite basic aspects of movement such as deference behaviour in stairways.

International conferences bring together researchers and computer modellers to specifically address the design and management of built spaces for human movement and safety, and computer models such as MassMotion (see pp38-40) and Legion now incorporate more realistic occupant profiles from field studies, reflecting culture, anthropometry, and type of setting.

Such models increasingly blend observation of what a changing population does with advances in fire dynamics and complex social and organisational processes. They can be tailored to almost any type of occupancy, to answer specific design, construction, or management questions.

**Designing for human movement and safety**

Research has established that people tend to follow familiar routes in a building, with the result that they may ignore carefully provided escape routes and go out the way they came in, even though it is longer, and perhaps crowded and less well-protected. The result of this well-known characteristic can be a building with costly but never-used stairs and corridors. Examples can be found in shopping centres (where they do at least have a servicing function), airport termini, and even schools.

The aim should instead be to avoid the separation of routine and emergency circulation. This will make it easier for users to navigate around, while having the potential to save expensive space for more immediate uses.

**Case studies**

**Beijing Olympics Water Cube:**

**Dual use of circulation and evacuation space using performance-based design**

As already noted, research shows that escape routes which are distinct from normal building circulation are often overlooked in an emergency. Building projects and management strategies which avoid this separation result in structures that allow for both efficient and therefore safer evacuation and optimal use of floorspace to increase user enjoyment.

At Beijing, the approach adopted to deliver value on these critical issues was detailed smoke modelling and egress analysis, the latter done using spreadsheet methods, peer reviewed with evacuation modelling software to cross-check results.

This increased the useful area by removing the need for dedicated internal fire corridors, and maximised the number of seats for the Olympic Games (by several thousand). Many more customers were therefore able to see the events than would have been permissible if prescriptive guidance had been adhered to. Dedicated fire egress provisions, including reduction in the number of exit doors, prevented the façade from having 200m of exit doors in Games mode, which would have been detrimental both to the architectural vision and to security.

Greater openness of the internal building layout was also possible. The Chinese building code includes a high degree of fire compartmentation (which would have meant a fire wall through the middle of the main pool hall), but the human movement and fire safety design allowed for interconnection of all above-ground spaces.

5. Interior of main pool at the Beijing Water Cube.
Not only have we been building higher, but it appears that all too many people have become physically incapable of walking out of these tall buildings quickly enough. It is unsurprising that research around the world is currently addressing building evacuation using lifts and escalators, which were once universally prohibited, but have the potential for rapid and “effortless” evacuation from a wide range of building types.

At the HSBC building, human movement under imminent catastrophic event conditions was addressed without expensive retrofitting of staircases and additional exits. The approach came from the client, to look at emergency evacuation post-9/11. Various studies of movement in stairs and the potential to use the passenger lifts in “down peak” mode, led to HSBC adopting a combined lift and stair system, which enables it to evacuate about four times more quickly than with stairs alone.
The Fehmarnbelt Fixed Link

The huge investment in transport infrastructure is not limited to the UK; increased provision of higher quality transport links is a global priority, with particular emphasis being placed on rail. Tunnels inevitably form an integral part of this and are an efficient way of covering large distances under, or through, difficult terrain. The proposed tunnel solution for the Fehmarnbelt Fixed Link across the Baltic Sea between the German island of Fehmarn and the Danish island of Lolland pushes the boundaries of immersed tunnel design, being over 18km long and accommodating both road and rail traffic.

One key area of this project involved evaluating the means of escape within the tunnel. The current design provides exit doors every 100m. This is a closer spacing than recommended by many European and International guidance documents, and aims to reduce the time occupants are in the incident tunnel by reducing the distance they have to walk to enter the adjacent non-incident tunnel. This helps to reduce the required safe egress time (RSET) for occupants.

King's Cross St Pancras Underground station renewal, London: Optimising circulation in crowded conditions

Massive investment in London’s transport infrastructure has presented a new generation of designers with the opportunity to create faster, friendlier, and more efficient Underground and rail stations. But safety standards are higher, the trains carry more passengers, and non-ticket revenue opportunities have to be maximised without impeding operations. The redevelopment of King’s Cross St Pancras Underground station shows what can be achieved by addressing developments in human movement and safety within building design and management.

A very detailed analysis of fire propagation, evacuation, and routine crowd circulation was undertaken, which included liaison with clients and their design team throughout. This helped the architects define a simpler, more intuitive layout and facilities, with better sightlines and a significant reduction in station congestion, while integrating retail space.

The result was the creation of several alternative exits and three new ticket halls (previously all passengers had to pass through just one, a major limitation highlighted by the 1987 King’s Cross St Pancras Underground fire). All routes are now both routine and emergency routes, and all platforms have alternative means of escape. What was a congested, crowded, and stressful daily experience for thousands of customers is now a safe and efficient throughput with minimal disruption.
To validate this, egress analysis was carried out, using both traditional hand calculation and computational analysis with Legion software. This was initially done as a test case, to see how the two methods compared. It was clear that with low populations the results compared well, but as the design populations increased, it soon became clear that the computational method produced higher egress times. Scrutiny of the results and interrogation of the model flow rates revealed that at certain positions (primarily, but not limited to the train exit(s) and cross-passage doors) the flow rates experienced for high population densities were much lower than assumed for the static, hand calculation method.

Going through this process highlighted flaws in the traditional methods of egress calculation; specifically that where high populations exist, with numerous "twists and turns” on an escape route, the flow rates experienced are typically much lower than would be expected. This exercise also proved the benefit of using a computational modelling method in what was seemingly a simple evacuation scenario.

Interaction with clients and stakeholders
Each project required extensive liaison and interaction with stakeholders to deliver these critical issues and design innovations.

For the Water Cube, unrivalled access to the whole range of engineering disciplines and modellers, a local office fluent in Chinese, and a strong daily co-ordination with the architects enabled successful project delivery.

For King’s Cross St Pancras, the client selected the fire engineers specifically because of their existing portfolio, which showed an in-depth knowledge of the station layout and workings, experience in defining and implementing fire strategies smoothly in high-occupancy buildings that continue to operate throughout, and unrivalled access to human movement and safety expertise. Many face-to-face meetings with design teams, engineers and approval authorities took place.

The Fehmarnbelt Fixed Link is still in the concept design stage and the decisions about whether or not to take the design to construction, and what form the Fixed Link may take, have yet to be made. Whatever the outcome, however, safety/egress issues will remain of the utmost importance.

The future
Escalators are the centrepiece of human movement in a wide range of public buildings and atria, and their safety record is impressive. Evacuation from sub-surface rail stations using escalators is gaining in regulator approval popularity. As yet there is little international agreement on this usage, and virtually no approval for evacuation using escalators in other public spaces. New research is required on human movement and safety across a wide range of buildings where escalators are used to safely carry many tens of thousands of people daily.

As buildings increase in size and complexity, the question of what is an appropriate evacuation strategy becomes more difficult. Whether occupants should stay put or move to a local place of safety, and what happens to them thereafter, are key questions for which research is still outstanding. How will such complex strategies be managed? Blending the all-important business continuity with safety design, communication procedures, management systems, and new research on human movement will be a major challenge in years to come.

References
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