Escaping with your life

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Abstract

Of the many horrors of September 11, 2001, the sight of people falling and jumping to their deaths from the Towers of the World Trade Center will not be soon forgotten by anyone watching. The sight brutally expressed the desperation of those trapped above the raging fires, unable or unwilling to descend through the wounded structures. Even in light of the eventual collapse of the structures, the terrible situation above the crash locations made very clear a fundamental failing of escape strategies of all tall and supertall buildings. In the event of a catastrophic compromise of the emergency fire stairs, people trapped above the disaster have no options for escape. Rescue from above is dangerous and extremely time-consuming and waiting for fire suppression can risk many lives and cause unimaginable suffering. Also, in light of the recent collapse of the World Trade Center towers in New York City, it is clear that there may arise situations in which the amount of time necessary for a full evacuation of a tall building exceeds the amount of time that the structure can resist instability and collapse. Therefore, there is an existing need to investigate building systems that provide augmented means that substantially increase the efficiency with which people may be evacuated and protected during these catastrophic events. This article proposes several augmentations of existing egress systems while accepting current net to gross floor area ratios necessary for these types of buildings to remain economically and operationally practical. Under moderate emergency conditions, such as small and localized fires, emergency systems in tall buildings have performed well. However, during catastrophic events tall buildings are challenged with exceedingly difficult egress scenarios, fire suppression demands and structural performance requirements. As a result of very large occupancies, limited floor space and the increasing heights of the most recent tall buildings, the challenge of quickly and completely evacuating the interior spaces of these types of buildings should again be addressed. Building codes, both local and national have established a high level of design and specification for fire ratings, alarms, communication systems, suppression technologies and evacuation plans that address the life-threatening conditions of a tall building emergency. This paper does not intend to question the effectiveness of these existing regulations. This proposals contained within are assessed in terms of their potential effectiveness in alleviating current problems during emergency situations as well as the practicality of their inclusion in both new designs and existing buildings.

1.1 Introduction

The modern tall building is one of only a select few architectural types that can legitimately claim a decidedly American origin. During the late 19th and early 20th centuries several buildings in the United States signaled a new age of structural engineering and architectural form at the service of increasingly dense and intense central business districts. The Carson Pirie Scott Department Store (Chicago, 1894), the Guaranty Building (Buffalo, 1895), and the Reliance Building (Chicago, 1895), among others, initiated the entry of the tall building into urbanism as a viable economic response to the pressures of the densification of modern central business districts. The first tall buildings were massive masonry structures with bearing walls that reached a thickness of 6-8 feet at their lowest levels. However, the rise of the tall building, as a new type of urban structure, truly began with the first steel structural frames [1][2][3]. The Woolworth Building (New York, 1913), one of the earliest structural steel frames, retained its title as world's tallest building for 17 years until the construction of the Chrysler Building. Eventually, engineers invented any number of structural technologies that made very tall buildings possible. A very tall building is normally referred to as *supertall* when it reaches 80 stories or more.

In concert with the development of structural technologies and safe elevators to lift occupied space ever higher into the sky came building systems to support and protect life. These systems include the strategies and technologies necessary for aiding in the safe and quick evacuation of people from a building that has become dangerous to its occupants. The regulation of the design of these structures, as with any legally occupied building, has been the mandate of the national and local building codes. However, because of the performance requirements of these specialized buildings, the designers, both architects and engineers, have consistently specified systems that have exceeded required code expectations. It is important to note that the performance demands that structural engineers have asked of their frames has often far exceeded the stated structural codes under which the design work was regulated. One reason for this is the obvious need to insure an extra level of care in responding to the demands of a building type so heavily occupied and affected by factors such as earthquakes and the variability of the lateral wind load. Many designs have exceeded the stiffness stipulated under building codes specifically to establish a generally accepted level of comfort for those working and living in very tall buildings. During the design of the World Trade Center, Leslie Robertson took into account detailed studies that stipulated the proportion of the building population adversely affected by various levels of lateral acceleration due to wind load. In other words, the culture of structural and life safety design for tall buildings has been one of innovation and specification that goes well beyond the legally regulated performance requirements of these types of buildings.

However, in response to the recent tragedy in New York City, the terrible collapse of not one but two of the largest structures in the world and the largest in the city, another round of evaluation needs to occur to continue innovation of emergency systems for tall buildings. This need is particularly pressing because of the anticipated new crop of supertall buildings to be built around the world. In the aftermath of the WTC collapse, some projects in their financing and planning stages may be postponed indefinitely, however many other projects will undoubtedly continue through design and construction. Currently, projects being planned include the Shanghai World Financial Center at 1,509 feet, the Center of India Tower in Katangi at 2,222 feet and 7 South Dearborn in Chicago at 2,000 feet. The World Trade Centers extended to the height of 1,420 feet (1,350 feet above grade + 70 feet below). If only these three planned towers are built, they would collectively accommodate a total population of something like 120,000 people.

1.2 Working assumptions of egress for tall buildings

Innovation in architectural technologies may be characterized as following a fitful series of small breakthroughs that lead to occasional paradigm shifts. With the invention of ever-higher structures has come a steady stream of improvement that has allowed designers to periodically discount any notion of an upper height limit. The recent few decades have shown that the actual limit to the height and bulk of tall buildings has been the amount of capital available for investment in such large projects - not the technology necessary to realize them.

Emergency systems have also evolved alongside the structure, exterior envelope, mechanical, vertical transportation, and interior partition and finishing systems of these large towers. Even though these systems have performed well, it is understood that these buildings are designed under certain fundamental assumptions that may not be compromised and are particular only to tall buildings. We will consider two primary assumptions here:

1. during an emergency event, the vertical egress path – the path of safe escape from the building - may not be critically compromised; that is, this egress path is the only route provided to persons that need to evacuate the building, Figures 1 and 2, and
2. the amount of space allocated to the egress path is sufficient, and therefore the amount of time for egress is not excessive, either for the structure to maintain its integrity as a load bearing and transfer system, or for any other necessary building system to perform properly to sustain life in the building.

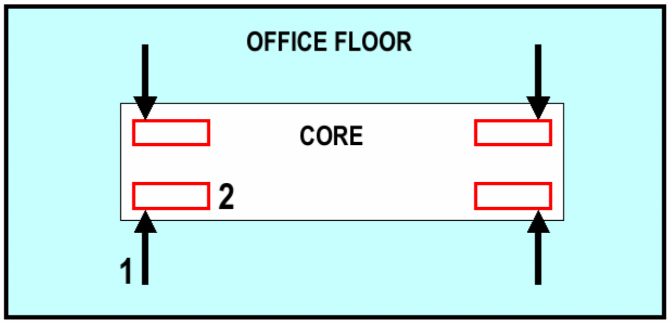


Figure 1: Typical tall building egress strategy

1: Egress entry
2: Rated fire stair

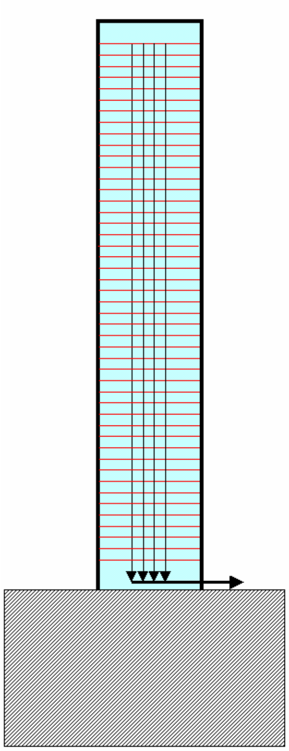


Figure 2: Typical tall building egress strategy

This paper specifically addresses these two assumptions by noting that very tall buildings may not sufficiently provide adequate egress space or alternative paths for evacuation given that the amount of time necessary for a full evacuation has been known to exceed 2, 3 and sometimes 4 hours. In addition, it is obvious that there always exists the potential for the vertical path to be severed. In that case, there is currently no good solution for quick evacuation of trapped persons. This is the issue that this paper addresses.

It is obvious that a tall building is like no other contemporary building type in that a significant amount of the volume of the building, usually the vast majority, occurs at heights that often far exceed the reach of even the tallest evacuation ladders. In any supertall building, at an average floor to floor height of 12 ft. 4 inches, the 80th floor is at a height of approximately 980 feet above grade. Even assuming that those at and below 80 floors could be rescued somehow, even if the regular egress path was compromised, those above 80 floors do not have an alternative path of travel to safety. Given the average level of occupation per floor of many supertall towers, this may leave many hundreds, if not thousands, of people trapped if the regular egress path is rendered, or perceived to be, impassable. Therefore, those above the emergency have little ability to evacuate. Ron Hamburger, chief structural engineer for ABC Consulting New York and a member of the performance-review team assigned by the Federal Emergency Management Agency to review the collapse of the World Trade Center, has stated that this particular situation requires attention [4]. In addition, augmented egress was identified as a primary concern by the FEMA team in its report to Congress submitted in May of 2002 [5].

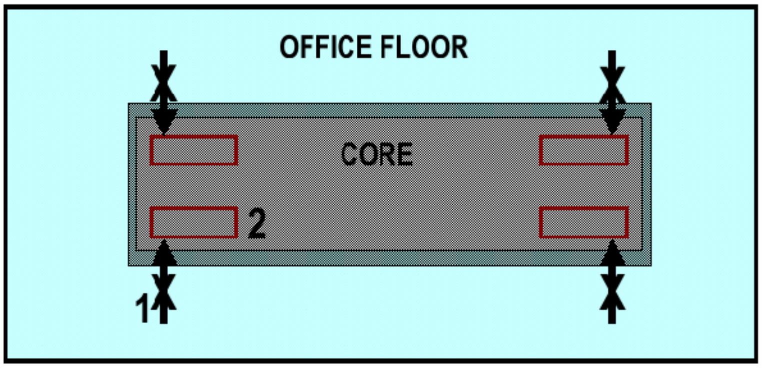


Figure 3: Compromised building egress within zones A and B

1: Egress entry
2: Rated fire stair

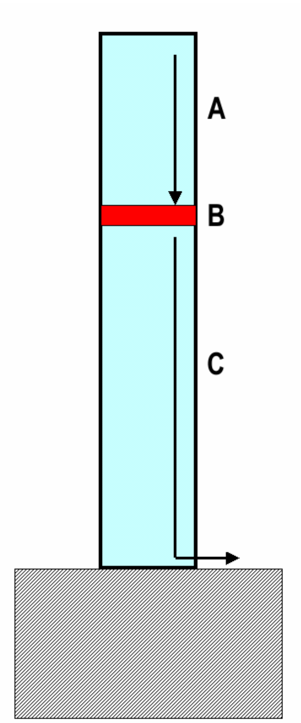


Figure 4: Building Zones

A: Above Event Zone
B: Event Zone
C: Below Event Zone

1.3 The Event Zone

For the purpose of addressing these issues, the study poses the following scenario in which an emergency event occurs within the shaft of a supertall structure.
In Figure 4, zone B designates the Event Zone; the volume of one or more floors in which a catastrophic event is occurring. Zone A corresponds to those occupied floors above the Event Zone. Zone C designates those floors below the Event Zone. In the event that zone B has become an impassable obstacle within the building, those persons above this area have very limited possibilities for quick evacuation. For the most part, accepted rescue strategy entails first the evacuation of individuals en masse, and then, treatment of the event zone by emergency personnel. Under these conditions, it is also possible to evacuate people within zone A from the roof with a helicopter. However, this strategy is risky and can only move a small number of people in discrete increments. In any case, those in zone A will not have the option of a quick evacuation. The occupied floors within zone B may or may not have the option of evacuation. The possibility for escape within this volume is highly dependent on the nature of the event and the status of the vertical egress volumes of the fire stairs and exits at each floor in this zone. Those in zone C may proceed to evacuate the building in the usual way. It is also possible for there to be an obstruction that prevents occupants of any particular floor to access the emergency stairs, Figure 3. In this case again, the occupants have no options for alternative evacuation.

Let us return to the two assumptions that we are addressing.

The first assumption is that the vertical egress circulation system, the fire stairs and the rated corridors leading to them, will not be compromised. These fire-rated enclosures are the designated paths for leaving the building under the protection of the shaft from higher temperatures, smoke and fumes. Those in the building that find themselves below the location of an emergency are in the best position to simply descend through the egress path and out into the public way. Those located above or at the same level as the event may or may not find that their path vertically downward is still intact. If the path is compromised, currently there is no good solution to this difficult situation. It is now clear that during the attacks on September 11, the vertical paths from those floors above the crash locations were either critically compromised or perceived to be impassable. Those above the crash location could not or did not feel that they could evacuate before the collapse of the buildings occurred. It is clear they either did not have this egress option or perceived it to have been rendered impassable. Given the severity of the explosion it is likely that the fire-rated shafts of many of the egress stairs were completely destroyed and rendered impassable. The strongest evidence of this are the telephone calls received from inside the building that suggest that those above the crash site knew that escape downwards was no longer possible. However, four people from above the crash locations made their way down the fire stairs. It is clear now that there still existed a single and possibly several egress stairs that were passable. The critical element in restricting people from using these stairs was the perception of impassability.

In addition, the stairs were all located in the central core of the building and it was a reasonable assumption to believe that the core, in its entirety, had been destroyed. There is no better proof of the desperation of those trapped above the crash locations than the horrific choice made to jump from the windows of the towers.

The second assumption is that the amount of space provided for egress has been sufficient for the quick and efficient evacuation of tall buildings. Again, indications from the recent events in New York and also from the bombing of those same buildings on February 26, 1993, seem to indicate that the space required for egress in tall buildings is simply inadequate for the rapid evacuation of the enormous population attempting to leave the buildings. There is the need to provide both a greater number of egress paths that contribute a substantial increase in the available egress path width over and above current practice. In addition, there is a need to provide for egress paths that provide an alternate route away from a damaged core. Finally, the strategy of phased evacuation of tall buildings needs to be revisited.

2.0 Redundant and Complementary Systems

In the days following the collapse of the towers, a number of articles were written in the popular press that speculated on ways in which to better evacuate persons trapped in tall buildings and fortify the structure of these types of buildings. While there have been opinions stated in and outside of the design and engineering professions that the future of the tall building [6] has dimmed significantly, the overriding reaction has been to acknowledge that tall buildings will continue to be built; as tall and taller than ever. The discussion has now shifted toward strategies in which to make the structures and evacuation systems of these buildings more robust. Various types of technologies have been cited as having a potential to improve the egress situation. While several of those technologies are mentioned here, the following sections are meant to emphasize the need for a reevaluation of the emergency egress systems that assist people during an emergency situation.

2.1 System 1: Alternate Egress Systems

It has been shown in a study by Fahy and Proulx [7], that the overall response to emergency situations is a complex combination of seemingly unpredictable human behavior, actions based on previous training, imperfect and conflicting information and many other factors often uniquely particular to the building and situation itself. The researchers identified 6 meaningful stages of response in the 1993 bombing of the World Trade Centers:

1. Investigate
2. Seek information
3. Alert or report
4. Assist others
5. Seek refuge
6. Wait

These stages suggest that the decision by each individual to evacuate is far from instantaneous. The decision to leave the building is arrived at after having considered various pieces of information from as many sources as possible. In 1993, the amount of time between the initial blast and leaving the building ranged from a few minutes to 4.8 hours in Tower 1 and again from a few minutes to 3.8 hours in Tower 2, as recorded in the study [7]. The study also recorded mean times of 11.3 and 25.4 minutes and median times of 5 and 10 minutes respectively. Clearly, the decision to evacuate was neither instantaneous nor unanimous.

Since the 1993 bombing the conditions within the fire stairs had been improved, with better lighting and signage. However, the evacuation of the towers was still not accomplished with the speed necessary to fully empty the buildings before their collapse. In 1993, over 70% of those from Tower 2 (in which accurate responses were received [7]), reported leaving the building in an hour or less. Only 40% of the respondents from Tower 1 were able to leave in an hour or less. Many of those that took longer to evacuate delayed in leaving the buildings after the initial blast. Egress strategies should begin to address this lag in the decision to evacuate by offering alternate routes in which to exit quickly by relieving pressure on the primary egress path. There is no doubt that evacuation times were improved during the recent partial evacuation of the towers. Within a very short time, most occupants of the tower that could evacuate did.

Even though egress times for the recent tragedy at the WTC were vastly reduced from the 1993 bombing, we can safely assume that this can be attributed, to some extent, to the increase in training that workers received after that attack. This heightened level of experience and training is not something that we can safely assume for all supertall buildings.

Most contemporary buildings designed in the U.S. are required to document a well-conceived egress strategy. The egress components, in outline, consist of the following elements [8]:

1. means of egress: a continuous and unobstructed path of travel from any point in a building or structure to a public way,
2. corridor: an enclosed passageway which limits the means of egress to a single path,
3. common path of travel: that portion of exit access which the occupants are required to traverse before two separate and distinct paths of travel to two exits are available,
4. exit: that portion of a means of egress which is separated from all other spaces of a building or structure by construction and opening protectives as required for exits to provide a way of travel to the exit discharge,
5. exit access: that portion of a means of egress which leads to an entrance of an exit,
6. exit discharge: that portion of a means of egress between the termination of an exit and a public way.
7. exit, horizontal: A way of passage from one building to an area of refuge in another building on approximately the same level.

All of these components together form the path of travel from any space inside the building to a public way. The egress path down through a tall building essentially consists of the path to the fire rated enclosure of the stair and the descent, within this rated volume, down to the public way. As buildings exceed 50 stories a substantial percentage of the floor space is consumed by the necessary shaftways for elevators and mechanical components as well as bathrooms and other service spaces. Therefore, the path to the fire stair is often easily made. However, once inside a stairwell the path down 50 or more stories is a long and arduous journey, made slower, in a building-wide evacuation, with congestion from the large population of the building. In addition, while the width of the stair may not decrease, by law, it is clear that the stair width does not increase enough for the accommodation of a variety of rates of descent. The slower evacuees necessarily substantially determine the rate of descent for all. To provide for an dramatically increasing stair width in proportion to the number of people in tall buildings would very quickly become a prohibitive incursion into the usable net office space of the building and render the building types uneconomical. As a result, tall buildings have come to accept a lower level of accommodation in minimum required egress dimensions as a necessary functional demand of the building type. Therefore, there exists a critical need to reexamine the possible ways in which a tall building may provide for the necessary width of egress travel appropriate for the population of the building. The following sections describe three types of ideas to enhance egress:

1. interior egress paths: using existing shafts to accommodate vertical egress paths systems,
2. exterior egress paths: using the exterior wall assembly to support additional egress systems, and
3. adjacent building egress paths: using adjacent buildings as an alternate path by bridging over to their exterior walls, roofs and accessing the adjacent building's interior egress paths.

All three types of additional paths are meant to provide a significant increase in egress area far beyond what can currently be proposed for tall buildings, for both complete building evacuation and the circumvention of localized failures in the primary egress path. These strategies will not impose a prohibitive incursion into the net area of the building's floor space.

2.1.1 Interior Egress Paths

Using various continuous interior volumes that are commonly found in all tall buildings, new and old, additional interior egress may be provided. Currently, fire rated stair shafts are the only path of egress in an overwhelming majority of tall buildings. This first proposal identifies the elevator shafts in tall buildings as additional egress pathways. These shafts are continuous volumes that currently sit idle during a fire. With the exception of the use of elevators by emergency rescue personnel, the elevators themselves are not operated during an emergency because of the risk to occupants.

Tall buildings may devote 10-15% of gross floor area to elevator shafts. The numbers of elevators necessary to practically service the population of the building particularly encumbers buildings above 50 stories. Elevators are available to be devoted to providing additional egress by containing, within their rated shafts, a folding stair that may be placed into service for use by the occupants during an emergency. In addition, one of these shaftways could be devoted to providing mechanisms for lowering disabled and physically compromised people down to the ground. The situation of a disabled person trapped in a tall building needs to be better addressed both for the individual and those that are encumbered to assist the person down stairs. This would free up further primary egress space for evacuation and also allow a separation between circulation devoted to emergency personnel and that dedicated to egress.
Other systems may also provide an alternative way in which to bring people down to the ground faster. Fire rated shoots made of fire resistant textiles can be placed within elevator shafts and quickly deployed to allow an alternate route down for people.

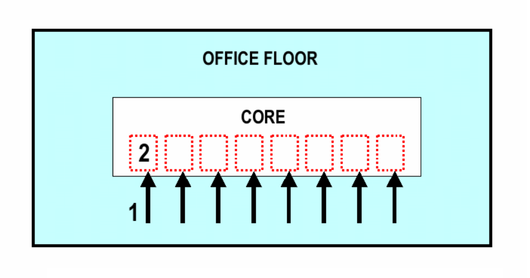


Figure 5: Elevator Shaft Egress Strategy

1: Egress Entry
2: Rated Elevator Shaft

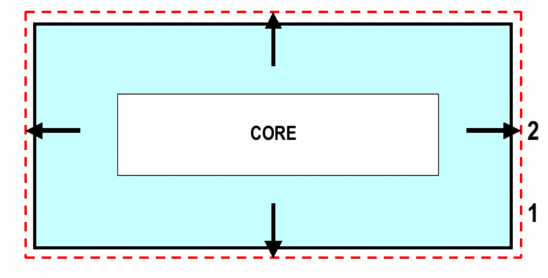


Figure 6: Exterior Wall Egress Strategy

1: Egress Path, across and down
2: Egress Entry

Another set of continuous shaft spaces are the mechanical servicing shafts for the building, but because these shafts are permanently occupied with air distribution ductwork and plenums and other equipment, these shafts are not practical volumes to be used for alternative egress paths. In addition, very tall buildings often contain more than one mechanical plant. These plants are distributed through the building on various floors making the shafts that are distributed from each not continuous throughout the entire building.

This particular augmentation of the vertical volume available for egress does not offer a solution to the situation in which all elements within the critical zone have been compromised. In that scenario, the elevator shafts would also become impassable. In Figure 4, the elevator shafts are assumed to be impassable as the emergency stairs are. In this scenario, that of a catastrophic severing of the egress path, additional strategies need to be employed to bypass the event zone. Any strategy that uses th core as the location for an egress path may risk becoming unworkable in the event that the core is severely compromised. Additional strategies are, therefore, required.

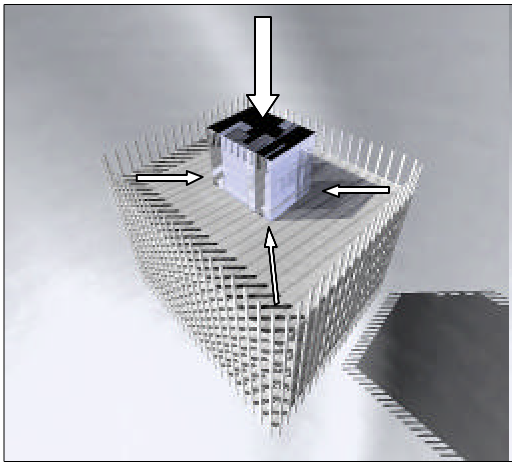


Figure 7: Egress concentrated at core

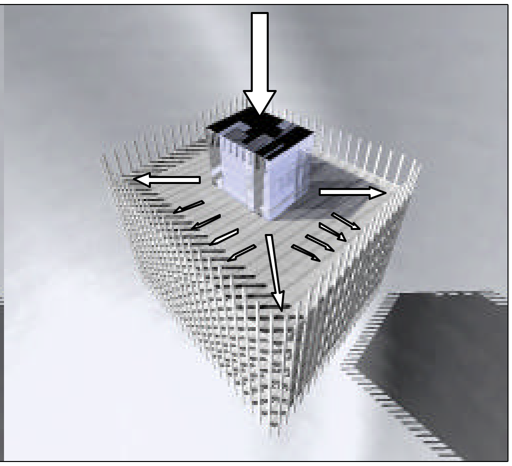


Figure 8: Egress also available at perimeter wall

2.1.2 Exterior Egress Paths

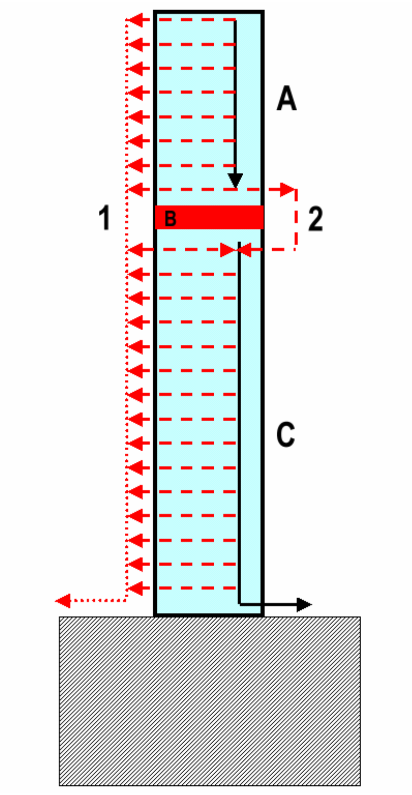
The exterior perimeter surfaces of tall buildings also offer a structural armature for the support of evacuation systems that could form an augmented egress strategy for tall buildings, Figure 8. This alternative egress provides additional paths to be used in the event of an emergency. These paths could be used in two modes depending on the need:

1) increased egress routes supplementing uncompromised egress paths, and
2) alternate egress routes in the event that the internal rated stair paths have been compromised.

The exterior (perimeter wall) egress system could provide a path down the full length of the building; Figure 9, path 1, or in the case of the second mode, as a path to circumvent the floors that have been rendered impassable within the event zone; Figure 9, path 2. In this second case, an exterior egress system serves as an emergency backup when the normal egress path is too dangerous to follow. In very tall buildings, this is a possible solution to a very real need that has not been addressed; the case of those persons caught above an impassable event zone. The most reasonable application of this system will be at those heights above the reach of ladder trucks.

2.1.3 Adjacent-Building Egress Paths

In situations of extremely high urban density, alternate escape routes need to be coordinated between adjacent existing and new buildings. These alternate paths would require only that a continuous route be provided from one tower over to another. In the case of many tall buildings, this strategy makes the most sense as restricted to the upper floors of the buildings thus providing an alternative to those that would require the most amount of time to egress the structure, see Figure 10.



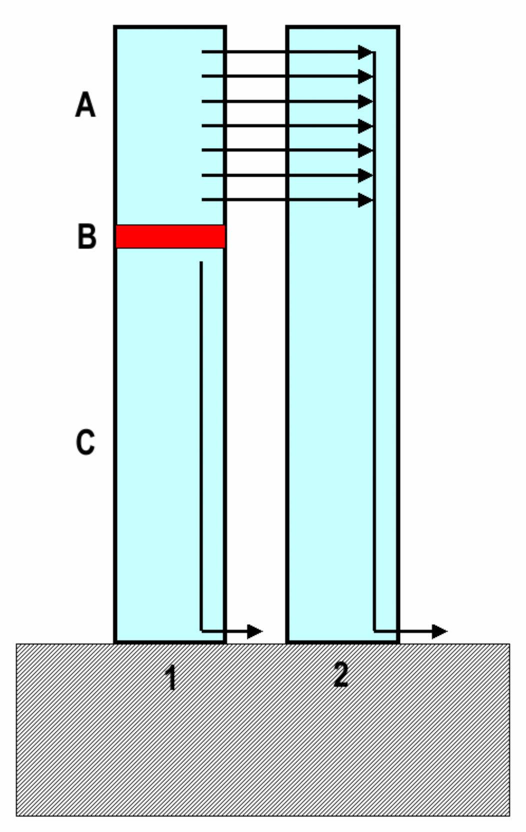


Figure 9: Exterior Egress Path

Figure 10: Egress path through an adjacent building

1. Building-wide alternate path
2. Event zone bypass

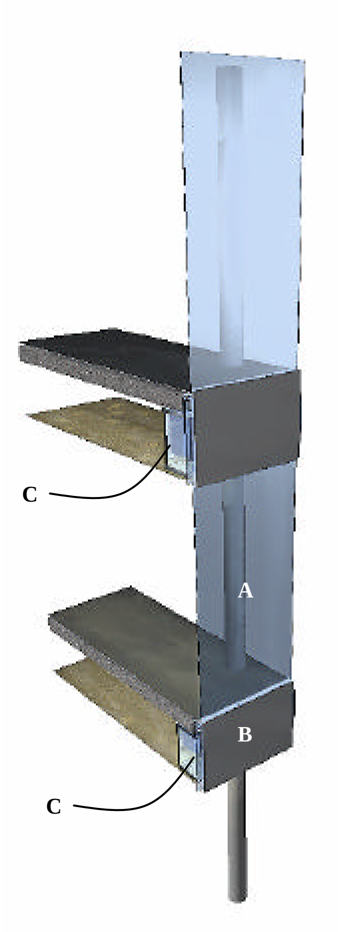


Figure 11: Section of curtainwall with integral perimeter wall escape mechanism.

A. Glazing system
B. Spandrel panel
C. Deployable escape device

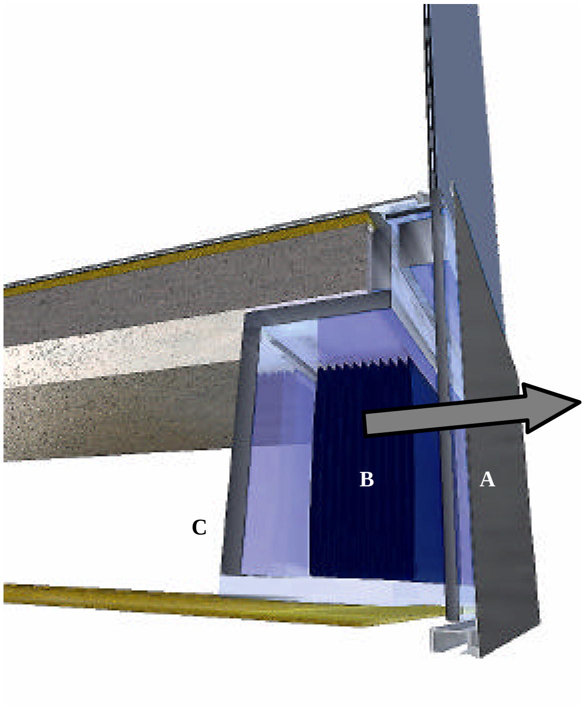


Figure 12: Detail at spandrel panel

A. Removable spandrel panel
B. Stored deployable escape device
C. Fire-protected enclosure

Three distinct configurations of the adjacent-building egress path are illustrated in Figures 13 A, B and C. These conditions are also illustrated to show that the more highly dense cities of the world already contain numerous opportunities for making links between buildings. As these cities become denser, these opportunities will only increase and the planning for cooperation between buildings will become more important.
The images shown are all taken in New York City.

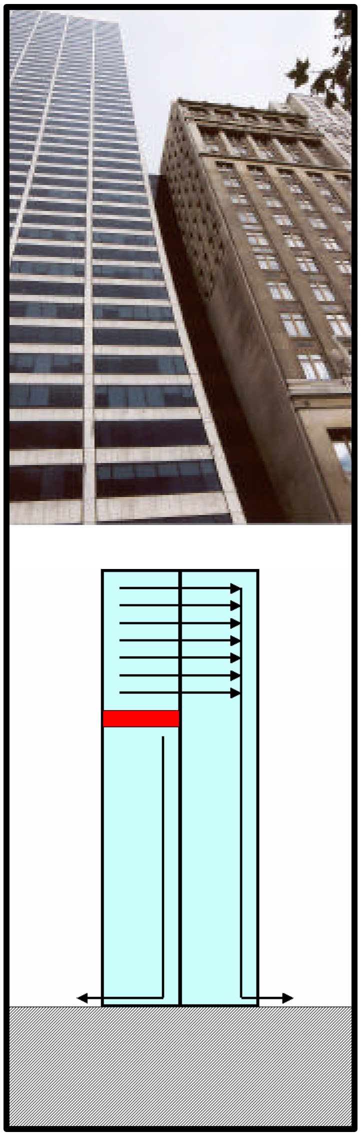


Figure 13A: Adjacent Building Egress

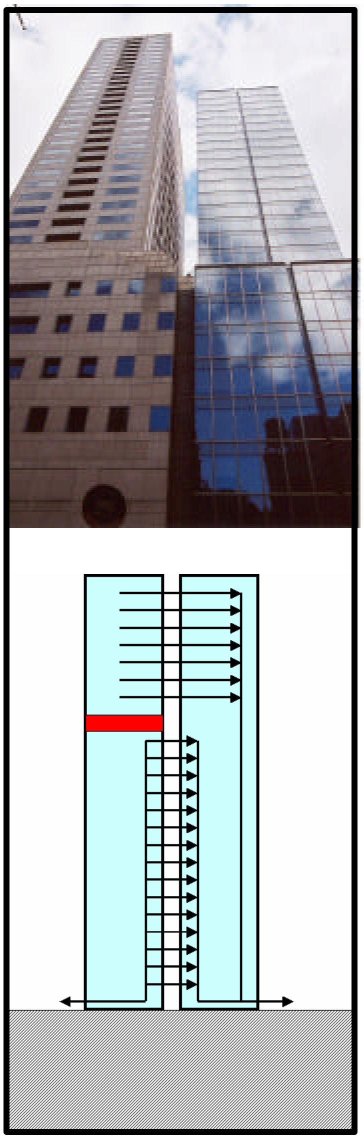


Figure 13B: Adjacent Building Egress

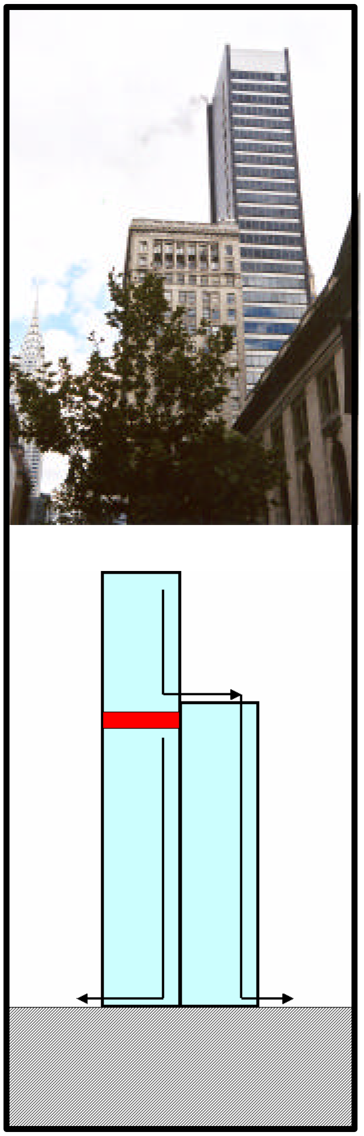


Figure 13C: Adjacent Building Egress

The bypass of the event zone requires devices that can be easily deployed and operated such that persons trapped under dire conditions can avail themselves of this alternate egress path. The materials best suited for this kind of device are fire resistant textiles of high tensile strengths and high impact tolerance. The best textile assembly would most likely involve several layers engineered to deliver and protect individuals from one floor to the next. For the sake of economy and the minimization of storage space necessary in the undeployed state, these types of devices may be best suited to delivery of individuals at maximum distances of several floors, say three or four floors at the most. Most fires in tall buildings have not extended much beyond several floors. In addition, there is also the possibility of linking individual lengths of escape chutes to make longer runs if necessary.

As shown in Figures 11 and 12, the material may be gathered and contained within the spandrel panel of the exterior curtainwall system. This space is typically free of mechanical ductwork, lighting and structure. Inserting a fire resistant cavity between the finish ceiling and the underside of the structural slab would be a relatively easy process, both in new designs and retrofits for existing buildings. The deployment of the system could be achieved manually, thus not relying on continuous power during an emergency. The fabric would drop down and out quickly assuming a tube form that would allow one to descend several floors at a time as shown below in Figures 14 and 15.

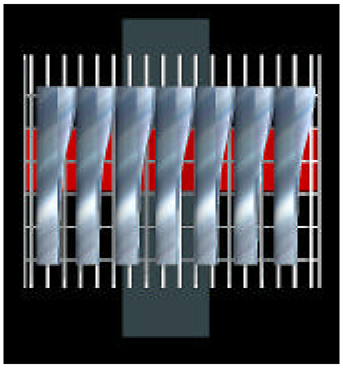


Figure 14: Elevation showing egress chutes deployed

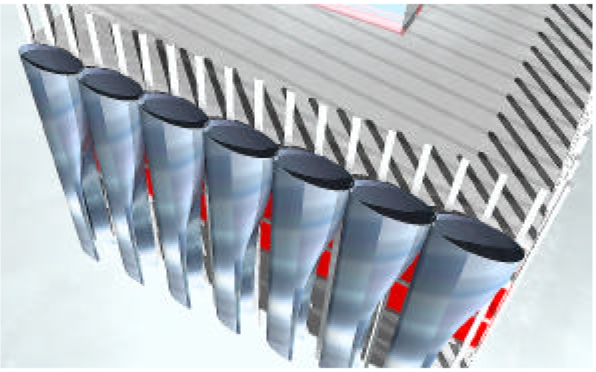


Figure 15: View from above

Several designs are shown for illustration purposes only in Figures 16 - 19. The images show deployable systems in different geometric configurations. The implications of such an approach are numerous and will require substantial further study. However, the intent can be clearly described as a non-centralized, manually deployed egress armature that contains either a tensile fabric that works by acting as an escape chute or contains within it a folding lightweight stair that is supported by the fabric membrane. The advantages of a fire-resistant fabric material are the ability to be easily deployed, lightweight and foldable. In addition, the space contained within the fabric enclosure may be pressurized from the ground and therefore smoke may be removed.

In addition, Figure 20 shows the side of a tower covered in an alternate egress system as shown deployed.

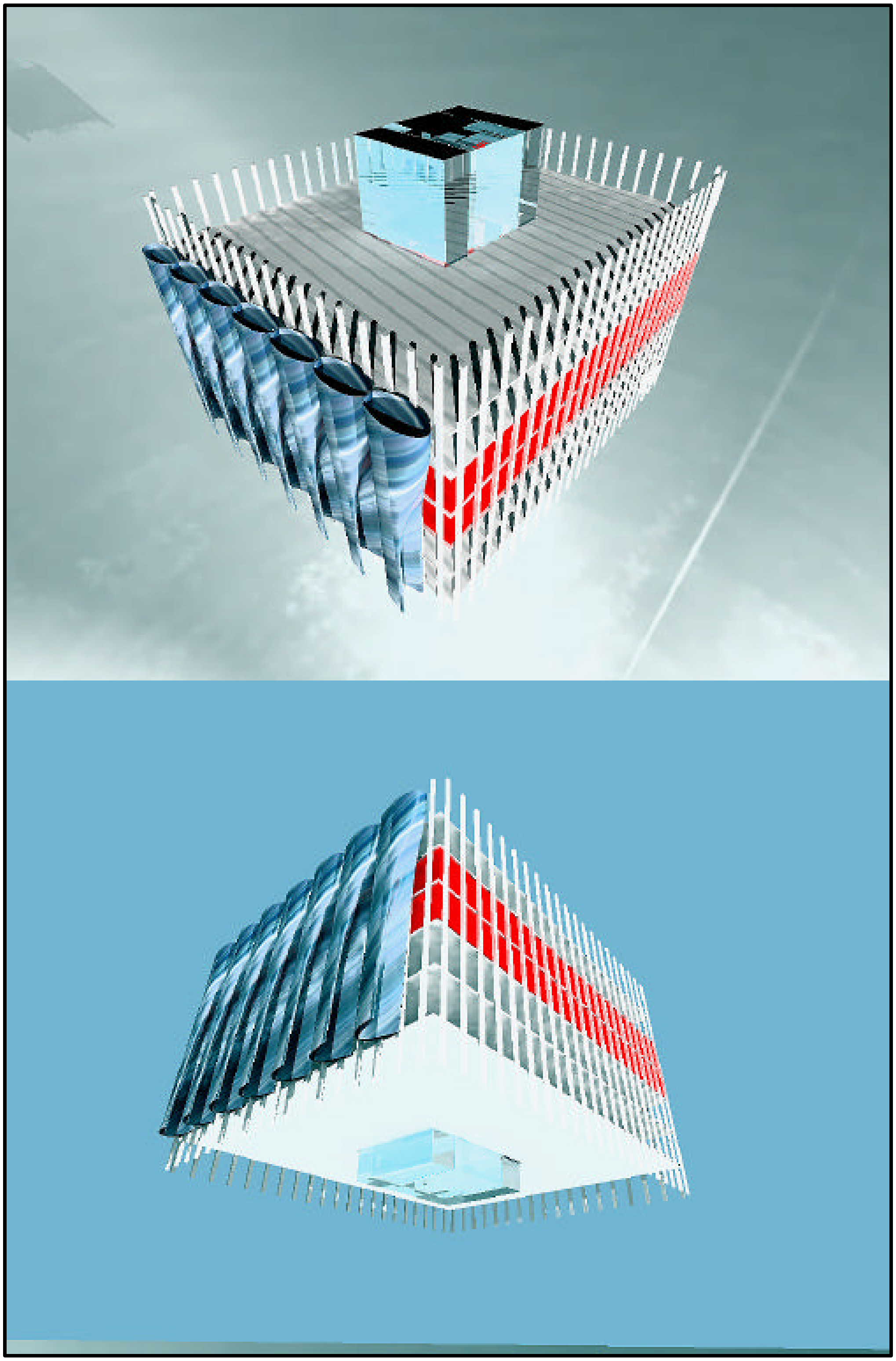


Figure 16: Deployed fire-resistant textile egress chute.

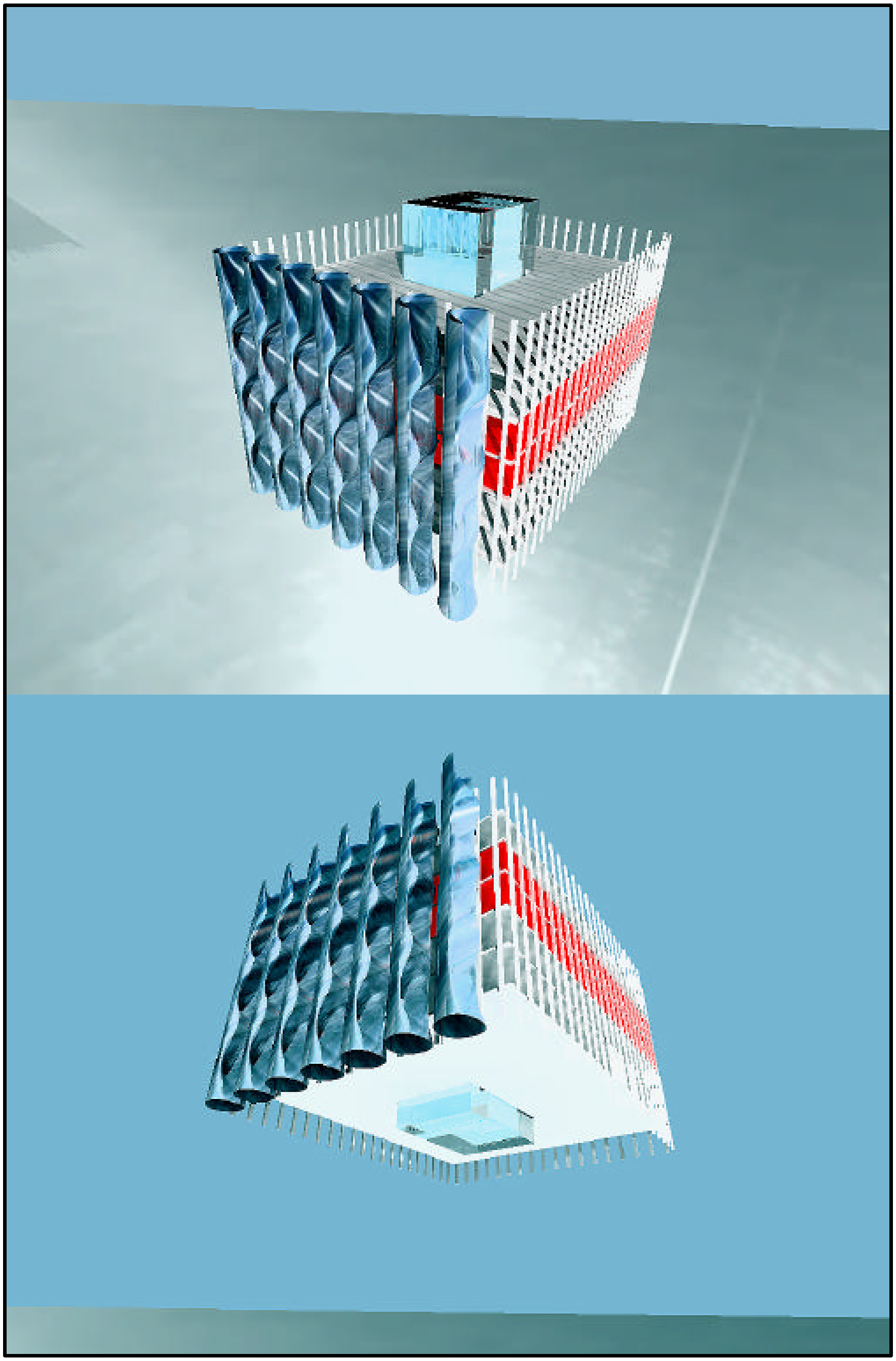


Figure 17: Deployed fire-resistant textile egress chute.

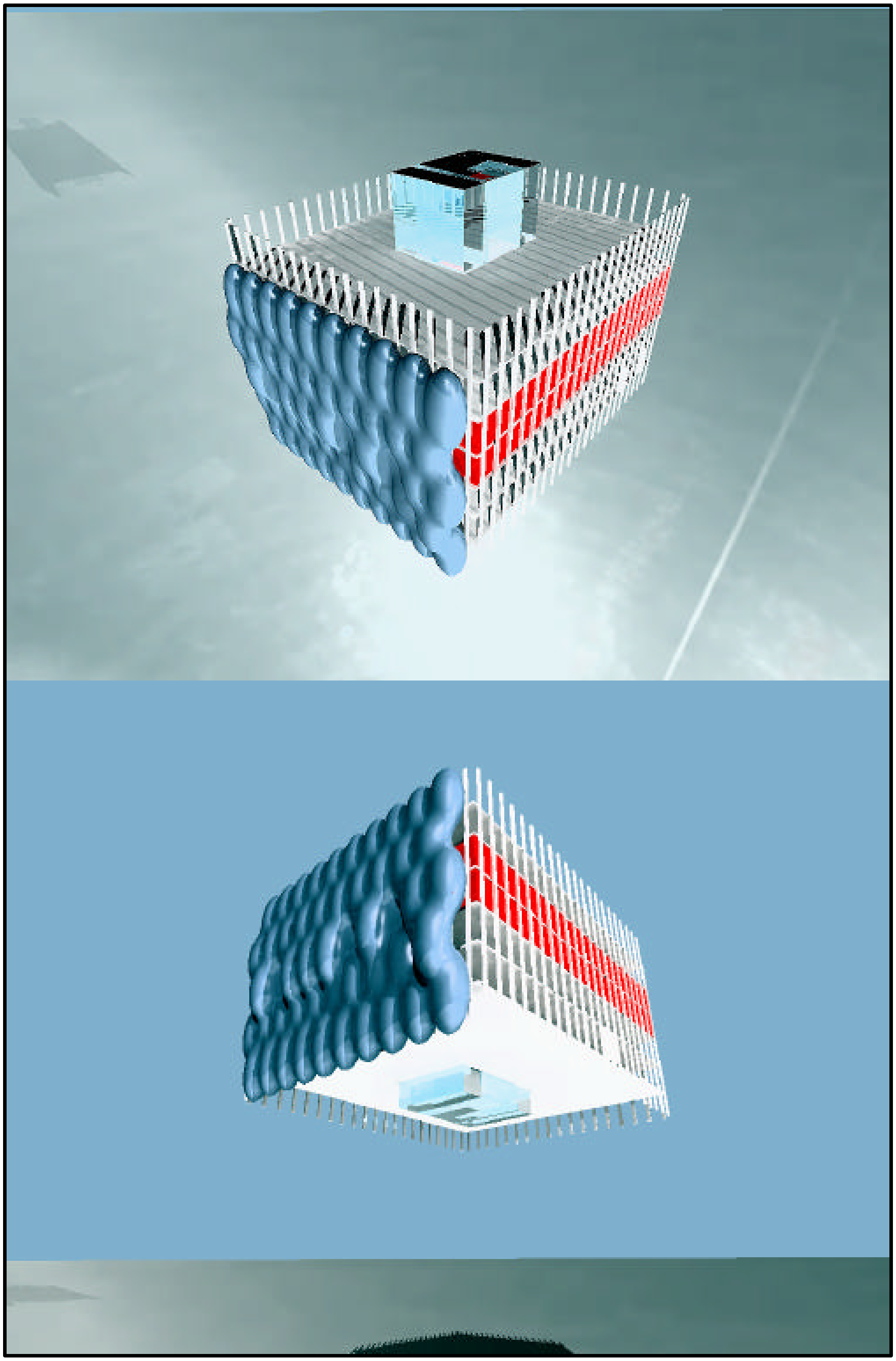


Figure 18: Deployed fire-resistant textile egress chute.

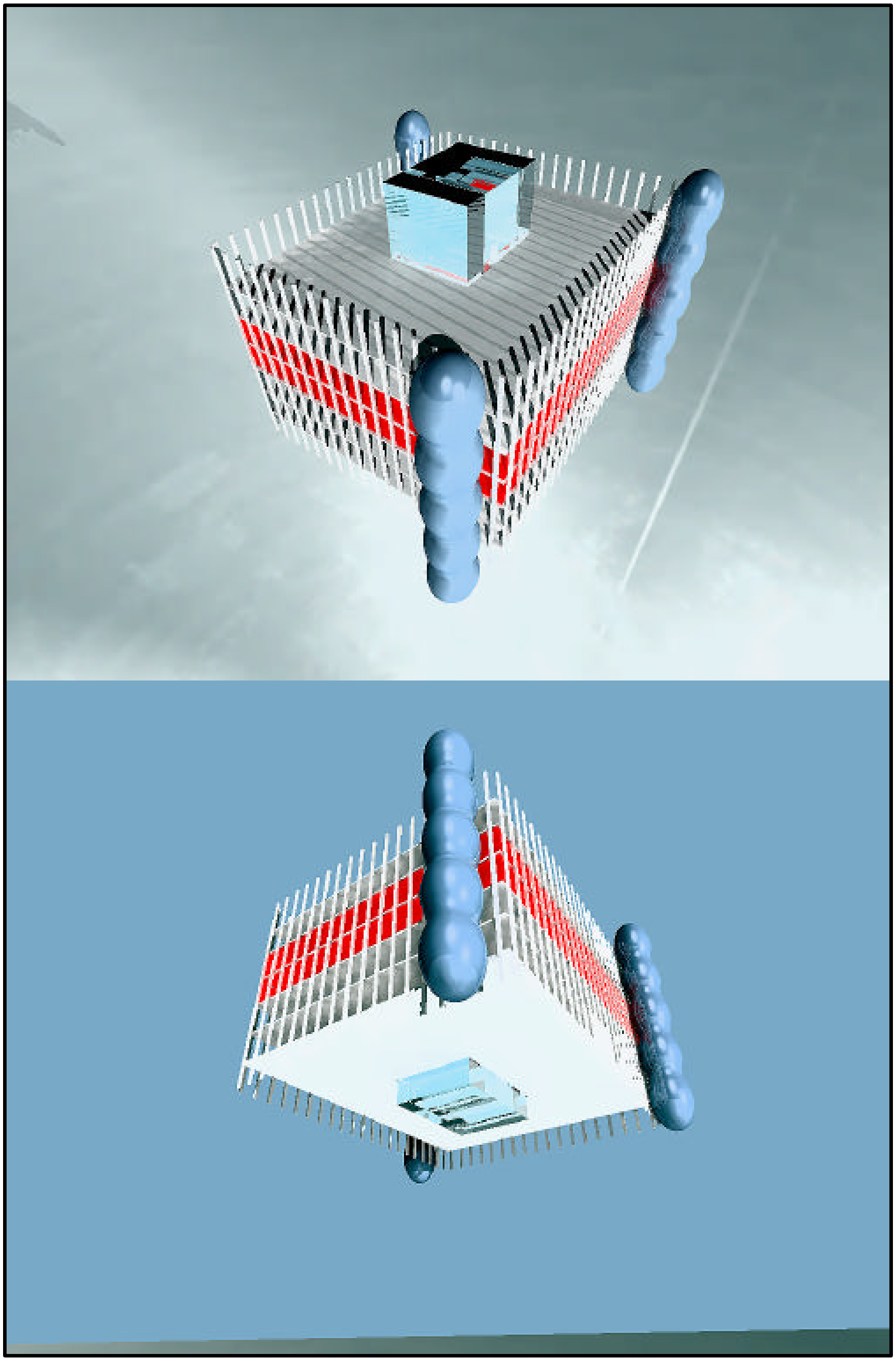


Figure 19: Deployed fire-resistant textile egress chute.

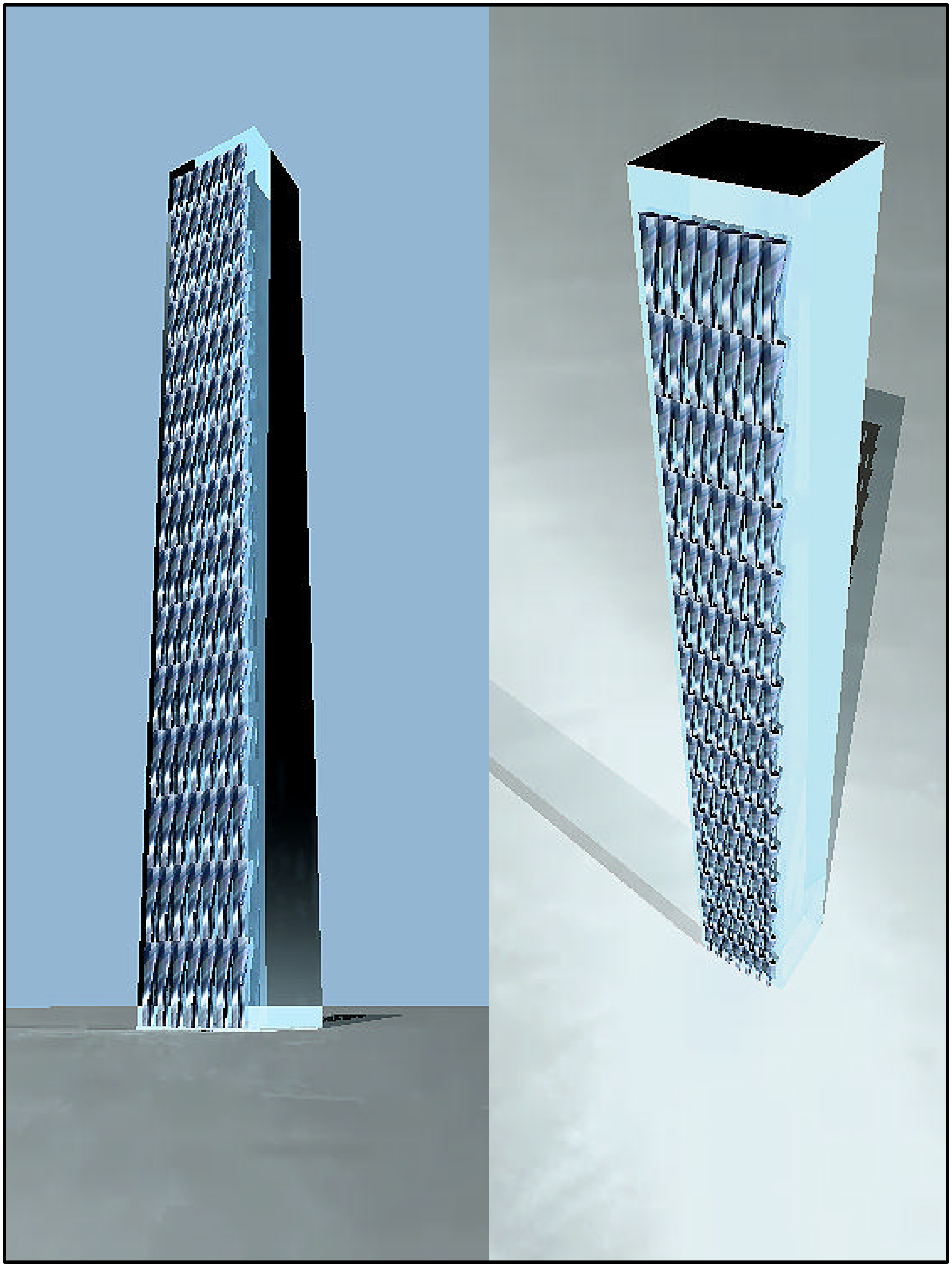


Figure 20: Deployed fire-resistant textile egress chute.

3. Experimental Rescue Devices

In contrast to the strategies mentioned above, several alternative technologies have been receiving some attention in the popular press [9][10][11]. These technologies include the following:

- ladders: deployable climbing devices for lowering oneself down to the ground,
- rope and pulley systems: especially relevant in the case of handicapped or otherwise incapacitated person rescue,
- escape shoots: woven fabric shoots that may be deployed for descent either to an adjacent building or down to the street below and while the limit is dependent on the manufacturer there is at least one company that markets a shoot that extends 15 floors or more,
- perimeter wall rescue vehicles: the adaptation of a common technology for the maintenance of the exterior envelope, platforms that descend from an armature secured to the building could provide a method for collecting and lowering trapped persons,
- rescue vehicles: a reexamination of rescue helicopters is being reconsidered and hovering platforms are also being investigated as ways in which to provide an exterior escape route that is completely independent of the building itself,
- emergency building escape parachute systems: individual low-altitude deployment parachutes used as a last resort in exiting a building.

Of these six alternatives, the fourth - perimeter wall rescue vehicles - would seem to hold the most promise because of existing perfected technology for automatic window washing and the ease of incorporating such a system into the exterior envelope of a tall building. The adaptation of such a platform would be a relatively trivial task. Furthermore, the rescue vehicle could be automated and deployed on any side of the building thereby avoiding parts of the exterior wall that may be engulfed in flames. Such a system could also be used to shuttle firefighters and their equipment up to locations in the building without the need for climbing stairs and without traveling through egress stairways being used by people trying to leave the building. In contrast, both the escape shoot and the independent rescue vehicle (helicopter or flying platform) engender far greater risks in transfer, balance and ultimately successful rescue of persons. Finally, the perimeter envelope rescue vehicle would require the least amount of physical agility of its users and would therefore accommodate the widest possible population of trapped persons. It could even be designed to assist with the rescue of those trapped in wheelchairs.

Ladders and rope and pulley systems are less attractive solutions because of the relatively high level of physical agility needed for each. In some circumstances however, the use of a rope and pulley system may assist in the delivery of handicapped persons down to the ground, as mentioned earlier.

While it is true that three people had successfully parachuted from the World Trade Towers in separate stunts over the years, the risks inherent in parachute systems are extremely high and can only be considered as an absolute last resort.
However, all of these ideas should be investigated for their possible utility in addressing the conditions of a catastrophic emergency.

4. Conclusions

A suite of egress strategies has been presented for the augmentation of safety systems for tall buildings. These ideas are meant to promote a general reevaluation of the methods and standards by which tall buildings are designed for egress in the event of a catastrophic event. The strategies presented here are intended to provide two things:

1. alternate paths of egress in the case of the critical compromise of the primary path, and
2. additional paths of egress to alleviate congestion in the primary path and provide a more efficient evacuation sequence for the entire building.

While there are numerous egress technologies that are receiving attention, the addition of redundant and complementary egress paths and their configurations, such that they may allow for passage around a critically damaged portion of the building, may substantially increase the safety of tall buildings under catastrophic emergency conditions. Further study is needed to develop those systems - lightweight deployable kinetic stairs, rescue vehicles and chutes - that may be incorporated into the exterior envelope and elevator shafts of existing and future supertall buildings. In any case, the issue of efficient passage to safety from any location in a tall building needs to be comprehensively addressed and a greater variety of egress options should be developed.

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