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THE ROLE OF ARCHITECTURE IN DESIGNING BUILDINGS SUBJECTED TO BLAST LOADS

BY

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Abstract. In recent decades by the increasing growth of terrorism, insecurity and risk of terrorist attacks have been increased. Terrorist attacks are often categorized as low probability, but potentially high consequence events. Thus one of the most important issues that must be taken into consideration while designing buildings is assessment and predicting such terrorist attacks and find ways to mitigate them. In the present paper potential terrorist attacks threatening buildings are identified and the architectural solutions to mitigate each of them are proposed using the books and standards.

Keywords: terrorist attacks; security measure; architecture; passive defense.

1. Introduction

Huge budgets are spent in constructing public and private buildings annually. At the same time a remarkable proportion of resources, assets and buildings are destroyed as a result of terrorist attacks. According to the Global Terrorism Index (GTI), these activities has increased dramatically with even conservative estimates suggesting a fivefold surge since the year 2000. This is a worrying statistics and shows that the risk of terrorist attacks have been increased. Thus, the necessity for designing buildings less vulnerable to such attacks have crucially grown. It is difficult to predict how, why, and when

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terrorist may attack. Therefore all the buildings are in potential danger of being a target and must be protected. The level of protection is identified by many factors such as the use of the building, and the number of occupants. In the first step threats and hazards are identified, studying the attacks that have occurred in past decades. Afterwards, for each threat respective countermeasures are extracted from standards and books.

2. Terrorist Attacks Identification

A terrorist or aggressor will analyze the building or target to determine the type of attack, type of weapon, and tactics to employ to defeat the building or critical mission/business function. Terrorists generally select targets that have some value as a target, such as an iconic commercial property, symbolic government building, or structure likely to inflict significant emotional or economic damage such as shopping mall or major seaport.

With any manmade hazard, it is important to understand who the people with the intent to cause harm are. A common method to evaluate terrorist threats is to analyze five factors: existence, capability, history, intention and targeting.

Existence addresses the questions: Who is hostile to the assets, organization, or community of concern? Are they present or thought to be present?

Capability addresses the questions: What weapons have been used in carrying out past attacks?

History addresses the questions: What has the potential threat element done in the past and how many times? When was the most recent incident and where, and against what target? What tactics did they use?

Intention addresses the questions: What does the potential threat element or aggressor hope to achieve?

Targeting addresses the questions: Do we know if an aggressor is performing surveillance on our building, nearby buildings, or buildings that have much in common with our organization?

By evaluating these five factors and checking whether they exist or not, the level of threat is identified.

Threat Level	Threat Analysis Factors				
	Existence	Capability	History	Intentions	Targeting
Severe (Red)	●	●	●	●	●
High (Orange)	●	●	●	●	❑
Elevated (Yellow)	●	●	●	❑	
Guarded (Blue)	●	●	❑		
Low (Green)	●	❑			

● Factor must be present ❑ Factor may or may not be present

Please note the DHS does not use these threat analysis factors to determine threat level.

SOURCE: COMMONWEALTH OF KENTUCKY OFFICE OF HOMELAND SECURITY

Their Methods can be forced entry tools, vehicles, and surveillance (visual/audio; stand-off or planted). Their weapons can include incendiary devices; small arms (rifles and handguns); stand-off military-style weapons (rocket propelled grenades or mortars); explosives; mail bombs; supply bombs (larger bombs processed through shipping departments); airborne and chemical, biological and radiological agents. These actions injure or kill people; destroy or damage facilities, property, equipment or resources; or steal equipment, material, or information. Table 1 provides a general profile of events associated with a spectrum of threat/hazards. Two of these threats which are more common and favorable than others are explosive blasts, including all types of bombs, and CBR agents. These threats are explained in depth later.

Table 1

Event Profile for Terrorist Threats/Hazards

Threat/Hazard	Application mode	Duration	Extent of effects static/dynamic
Improvised Explosive Device (Bomb) • Stationary Vehicle • Moving Vehicle • Mail • Supply • Thrown • Placed • Personnel	Detonation of explosive device on or near target; *via* person, vehicle, or projectile.	Instantaneous;	Extent of damage is determined by type and quantity of explosive. Static
Chemical, Biological, Radiological Agents	Liquid/aerosol contaminants can be dispersed using sprayers or other aerosol generators.	CBR agents may pose viable threats for hours to weeks, depending on the agent and the conditions in which it exists.	Contaminants can be carried out of the initial target area by persons, vehicle, water, and wind.
Arson/Incendiary attack	Initiation of fire or explosion on or near target via direct contact or remotely *via* projectile.	Generally minutes to hours.	Extent of damage is determined by type and quantity of device/accelerant and materials present at or near target.
Armed Attack	Tactical assault or sniper attacks from a remote location.	Minutes to Days.	Varies based upon the perpetrator's intent and capabilities.
Nuclear Device	Detonation of nuclear device underground, at the surface, in the air or high altitude.	Light/heat flash and blast/shock wave last for seconds; nuclear radiation and fallout hazards can persist for years.	Initial light, heat, and blast effects are static and fallout of radioactive contaminants may be dynamic.

Unauthorized Entry • Forced • Covert	Use of hand or power tools, weapons, or explosives, or use of false credentials to enter a building.	Minutes to hours, depending the intent.	If the goal is to steal or destroy physical assets, or disrupt operations, or take hostages the damage may be long lasting.
Surveillance	Stand-off collection of visual information using cameras or high powered optic, acoustic information using directional microphones and lasers.	Usually months.	This is usually the prelude to the loss of an asset. A terrorist surveillance team spends much time looking for vulnerabilities and tactics.

2.1. Explosive Blast

Explosive events have historically been a favorite tactic of terrorists for a variety of reasons and this is likely to continue into the future. Ingredients for homemade bombs are easily obtained on the open market as are the techniques for making bombs. Also, explosive events are easy and quick to execute. Explosives include homemade and stolen industrial and military varieties, packaged from small to very large (mail bombs to vehicle bombs).

When an explosion occurs, a shockwave consists of highly compressed hot air is created as a result of a chemical reaction which travels radially outward from the source at supersonic velocities. The pressure of shockwave decrease rapidly (with the cube of the distance) as it expands. Also pressure decays rapidly over time so that it vanishes in in thousands of a second or milliseconds.

Despite uncertainties about the extent and severity of damage in an explosive event, it is possible to give some general indications of the overall level of damage and injuries to be expected, based on the weapon size, measured in equivalent pounds of TNT, and the standoff, and the assumptions about the construction of the building.

The air shock wave is the primary damage mechanism in an explosion. The pressure it exerts on building surface may be several orders of magnitude greater than the loads for which the building is designed. The explosion pushes on the exterior walls at the lower stories and may cause wall failure and window breakage. As the shock wave continues to expand, it enters the structure, pushing both upward and downward on the floors. If the progressive collapse is initiated, it typically occurs within seconds.

Typical damage types that may be expected include:

- localized failure of the floor system immediately below the weapon;
- Damage and possible localized failure for the floor system above the weapon;
- Damage and possible localized failure of nearby concrete and masonry walls;
- Failure of nonstructural elements such as partition walls, false ceilings, ductwork, and window treatments;
- Flying debris generated by broken glass, furniture, computer equipment, and other contents. High-velocity flying debris, especially glass fragments have been shown to be a major contributor to injuries in such incidents.

2.2. Chemical, Biological, and Radiological Agents

CBR agents are used in two ways: 1. water contaminants, 2. air-borne

Three types of air-borne hazards are:

1. A large exterior release originating some distance away from the building (includes delivery by aircraft).

2. A small localized exterior release at an air intake or other opening in the exterior envelope of the building.

3. A small interior release in a publicly accessible area, a major egress route, or other vulnerable area (*e.g.*, lobby, mail room, delivery receiving).

Like explosive threats, chemical, biological and radiological (CBR) threats may be delivered externally or internally to the building. External ground-based threats may be released at a standoff distance from the building or may be delivered directly through an air intake or other opening. Interior threats may be delivered to accessible areas such as the lobby, mailroom, or loading dock, or they may be released into a secured area such as a primary egress route.

The best defense is to be alert to signs of a release occurring near you. The signs of air contamination are: observing a suspicious cloud, or smoke near ground level, hear an air blast, smell strange odors, see birds or other small animals dying, or hear of more than one person complaining of eye, throat or skin irritation or convulsing.

Chemicals will typically cause problems within in seconds or minutes after exposure, but they can sometimes have delayed effects that will not appear for hours or days. Symptoms may include blurred or dimmed vision; eye, throat, or skin irritation; difficulty breathing; excess saliva; or nausea. Biological and some radioactive contaminants typically will take days to weeks before symptoms appear, so listen for official information regarding symptoms.

3. Three Layers of Defense

The FEMA/DHS Risk Management Series of publication uses the concept of layers of defense as a means of protection against terrorist attacks (Fig. 1). Considering these layers is a traditional approach in providing security that has been used since ancient times to protect the occupants of a fortress or a castle.

Each security layer include its own specific strategies but methods of defense are also sometimes shared between adjoining layers.

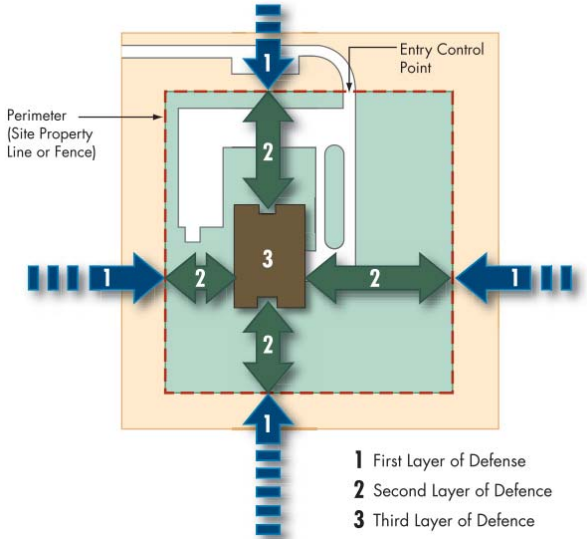


Fig. 1 – Three layers of defense.

The first layer of defense refer to the neighborhood and community surrounding the site, including building construction types, occupancies, and the nature and intensity of adjacent activities. The line of demarcation between the first and second layers is the defended perimeter. It is important that the designers study the surroundings of the site to identify potential threats. Investigation of the surrounding should include overhead features such as overlooking buildings, and tall structures, together with underground utilities and tunnels and installation of risk mitigation measures.

Second layer of defense refers to the space that exists between the defended perimeter and the assets that require protection. Perimeter security can be augmented within the site by the placement of buildings; site circulation to prevent high-speed vehicular approach; landscape measures such as earth berms to deflect blast; and the provision of stand-off distance. In addition, parking, pedestrian walkways, security lighting, signage, and site utilities are subject to security design. The primary strategy in planning the second layer of defense is

to keep terrorist away from inhabited buildings, since blast loads decrease rapidly with distance.

The third layer refers to the protection of the asset itself. Elements of this layer of defense include architectural design, structural system, building envelope, mechanical system, electrical systems, and fire alarm systems. Countermeasures and solutions proposed in this paper are mostly about this layer and especially architectural design.

4. Physical Security Measures

The primary focus of security measures described in this paper is on building shape, placement, exterior ornamentation, and functional layout of the interior. Physical security measures include ways which help to prevent terrorist attacks and relevant damages. If properly implemented, physical security measures will contribute toward the goals listed below in prioritized order.

- Preventing an attack
- Delaying the attack
- Mitigating the effects of the attack

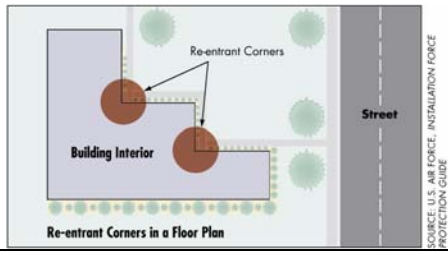
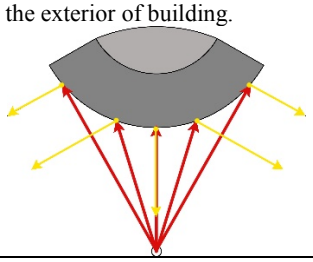
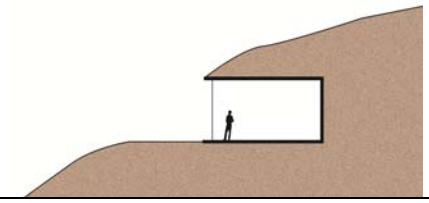
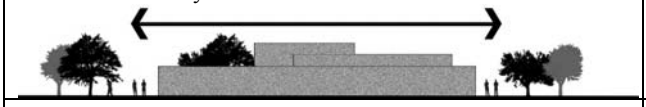
The measures should be as unobtrusive as possible to provide an inviting, efficient environment that does not attract undue attention of potential attackers. Also security design should be considered as a part of the overall design process to avoid conflicts with other dimensions of design such as natural hazard mitigation, fire protection, energy efficiency, and aesthetics. Another important issue that matters are costs (initial and life-cycle costs) of the measures implementation. There should be a trade-off between the desired level of protection and the costs. The decision depends to a large extent on the use of the building and functions, number of occupants, and the threat level.

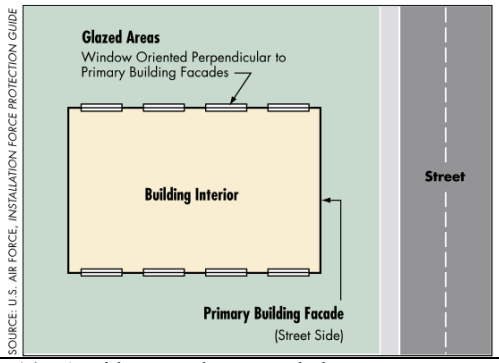
Each type of terrorist threat require its protection measures but in some cases a countermeasure can be effective for other types of threats either. Table 2 present a list of general architectural security measures, identifying what kind of threats they are actually preventing.

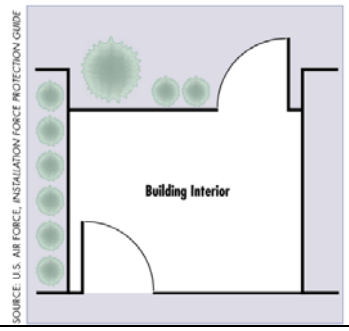
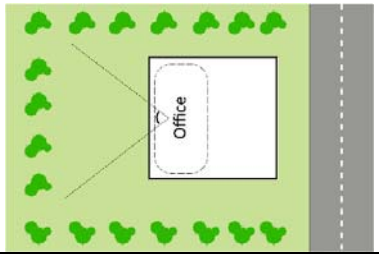
Table 2

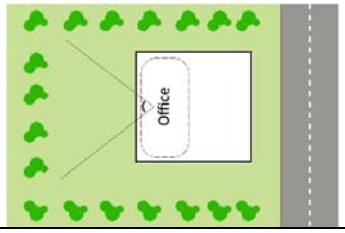
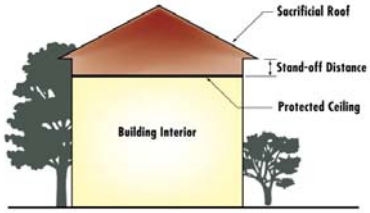
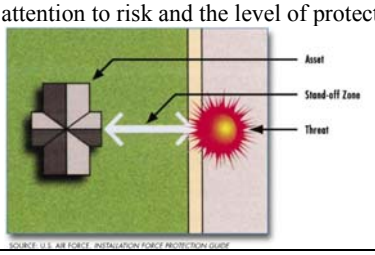
Physical Security Measures and Correlation to Threats

■ The symbols indicate which of the protective measures shown in the left-hand column can be effective in countering the types of threats indicated across the top of the chart.	Explosive Device(Bomb)	CBR Agents	Arson/Incendiary attack	Armed Attack	Nuclear Device	Unauthorized Entry	Surveillance

	Explosive Device(Bomb)	CBR Agents	Arson/Incendiary attack	Armed Attack	Nuclear Device	Unauthorized Entry	Surveillance
1. Distribute people, assets, and operations across a wider area.	■		■	■			■
2. Use vegetation, terrain, and other screening elements.	■						■
3. Avoid re-entrant corners. 	■						
4. Use convex shapes rather than concave shapes for the exterior of building. 	■				■		
5. Consider earth-sheltered design. 	■		■		■		■
6. Orient buildings horizontally rather than vertically. 	■			■	■		■

	Explosive Device(Bomb)	CBR Agents	Arson/Incendiary attack	Armed Attack	Nuclear Device	Unauthorized Entry	Surveillance
7. Locate key assets as far into the interior of a building as possible. 	■		■	■			■
8. Place the ground level floor 4 feet above grade.	■						
9. Avoid eaves and overhangs.	■				■		
10. Place parking areas outside the main footprint of the building.	■						
11. Place areas of high visitor activity away from key assets.		■	■	■		■	■
12. Do not collocate high-risk facilities with lower risk tenants.	■	■	■				
13. Orient glazing perpendicular to the primary façade. 	■				■		■
14. Avoid exposed structural elements.	■		■				
15. Eliminate the hiding places within the building.	■	■					■
16. Physically isolate lobbies, mailrooms, loading docks, and other entry and storage areas from the rest of the building.	■	■	■			■	■

17. Stagger interior doors and offset interior and exterior doors. 	■				■		
18. Place stairwells for emergency egress as far as possible from areas where blast might occur.	■						
19. Use air-tightening techniques in combination with building pressurization.		■					
20. Use simple geometries with minimal ornamentation.	■				■		
21. Do not place windows adjacent to doors.						■	
22. Minimize the number and the size of windows in façade.	■	■					■
23. Consider using laminated glass in place of conventional glass.	■				■		
24. Consider placing guards across window openings.						■	
25. Offices should be placed or glazed so that the occupants cannot be seen from an uncontrolled area. 							■
26. Consider placing guards across window openings.						■	

	Explosive Device(Bomb)	CBR Agents	Arson/Incendiary attack	Armed Attack	Nuclear Device	Unauthorized Entry	Surveillance
27. Offices should be placed or glazed so that the occupants cannot be seen from an uncontrolled area. 							■
28. Design buildings with a sacrificial sloping roof that is above a protected ceiling. 	■				■		
29. Elevate the fresh air intakes.		■					
30. Consider "shelter-in-place" rooms in the inner part of the building with no exterior windows.		■	■				
31. Consider hardened entry-control stations.	■			■		■	
32. Limit the number of doors used for normal entry/egress.						■	
33. Use appropriate stand-off distance with due attention to risk and the level of protection. 	■						
34. Use fire resistive construction technique.			■				

5. Conclusion

Based on the Global Terrorism Index, with the daily increase of terrorist activities, one of the most important hazards threatening people and assets is terrorism. Although terrorist attacks rarely happen and are not predictable, they can cause severe damages if neglected and not prepared for. Thus, different types of threats should be identified and analyzed to propose appropriate security measures to mitigate them. One of the most powerful tools to prevent such threats is architecture. If these threats are considered during the architectural design process and some cost-effective countermeasures are implemented according to the level of protection and threat levels, possible damages diminish to a huge extent. The architectural countermeasures can be devised and implemented with different levels of effectiveness. But by using some general measures provided by standards a desired level of protection can be achieved.

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ROLUL ARHITECTURII ÎN PROIECTAREA CLĂDIRILOR SUPUSE LA ACȚIUNI DE TIP EXPLOZIE

(Rezumat)

În ultimele decade, lipsa de siguranţă şi riscul unor atacuri armate a acrescut datorită creşterii ameninţărilor atacurilor armate. Aceste tipuri de atac sunt deseori considerate ca având o probabilitate mică de a se petrece dar, în acelaşi timp, cu consecinţe din cele mai nefaste. De aceea, una din abordările importante în momentul

proiectării unei structuri de construcţii este aceea de a evalua efectele unui asemenea atac şi găsirea de soluţii pentru reducerea prierderilor provocate. Lucrarea de faţă prezintă câteva soluţii arhitecturale de diminuare a efectelor unor asemenea atacuri.