Building Design Information and Requirements for Crowd Safety During Disasters

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Abstract

Building design requires the consideration of interaction of people with each other and the space. It is essential to consider dynamic information on movements and behaviours of users in buildings in addition to the static data that specify shape and dimensions based on the numbers of occupants and objects within the space. In public buildings, ensuring the safety and security of the occupants is even more challenging, especially during emergency situations and disasters where speedy and safe evacuations of large crowds from densely populated areas is essential. This research seeks to establish the scope for enhancing the safety of building occupants through the improved design of the built environment to better cope with extreme events, focusing on design information that is based on crowd behaviour in emergency situations. Within this context, critical safety issues are explored such as way finding, crowd flow, control, management and communication. The lack of dynamic information in building design, the potential use of crowd modelling techniques in improving designs for the safety and security in large public spaces during emergency events are highlighted, and case studies conducted to collect data on exit preference of people during building evacuation are presented. The research is based on an extensive literature review and interviews with safety, security and building design experts. It identifies a methodology to integrate dynamic information in building design with regard to crowd safety during emergencies. These are expected to have an impact on the development of design guidelines, codes and standards for public buildings.

Keywords: disaster mitigation, building design information, crowd management, safety, security

Introduction

The fundamental principle for safety in built environment is to ensure that the occupants in a building are safe during emergency events as well as the normal conditions. The contributions of architects and civil engineers for disaster management can have various approaches from producing short-term solutions (such as providing emergency shelters for the victims, design and construction of short-term housing), to long term actions for future developments (such as building new disaster resistant buildings or rebuilding damaged structures after the formal assessment of damage in the built environment) (Brown and Downey, 2006). Safety issues considered in designing buildings, sites and venues can be listed as but not limited to layout, way finding, crowd flow, segregation systems, construction systems and materials, and communication. Fulfilment of building code requirements for these issues is not an assurance to efficient functioning of buildings during everyday use and emergency situations (Fruin, 1993). Over-reliance on standards may limit the designers to fully express their design ideas or to develop better design solutions for special cases. This over-reliance may also create a danger by limiting their responsibility, causing idleness by letting them avoid some design issues because they are not stated in standards or codes of practice (Hale, et. al, 2007). Within this context, this research intends to contribute to mitigation against impacts of extreme events focusing on dynamic building information associated with safety and security issues. The next section clarify the aims and objectives of the research followed by an explanation of building safety and security issues associated with emergencies. Next, the internal and external building design requirements for extreme events are explored. The findings from the case studies on exit preference during the evacuation of large buildings are then presented.

Research Study

The aim of this research is to enhance safety and security through the improved design of the built environment to better cope with extreme events; and study crowd behaviour in emergency situations in order to develop guidelines for the design and refurbishment of large circulation areas.

Objectives of the research

The research objectives include:

- Review requirements and procedures for crowd safety during emergencies, and building design information, guidelines and standards used when designing new buildings for safety within large public areas.
- Review people flow simulation tools and techniques to establish their suitability for use within the context of crowd modelling for emergency events.
- Define crowd safety requirements in emergency events.
- Customize a suitable crowd modelling software and conduct tests on a number of emergency scenario based case studies.
- Define guidelines that specify improved designs that ensure better safety of users during emergency events within large public spaces such as airports and railway stations.

Methodologies

The methodologies used in this research include an extensive literature review; interviews with the safety and security experts; identification of people's behavior via observations through camcorders and CCTV records; questionnaire surveys; identification of design failures and recommendations for design solutions to mitigate the impacts of emergencies through crowd modeling scenarios. The literature review was on crowd dynamics, current building design codes, standards and guidelines, and building design requirements for safety and security of people during extreme events. The case studies aimed to explore the behavior and exit preferences of people through camcorder recordings and questionnaires.

Review on safety and security in buildings during emergency events

Geis (2000) highlights that the majority of human and property losses occur during extreme events because of inappropriate designs which contributes to the problem rather than to the solution. In order to minimize the impacts of emergency events and hazards in buildings, the building design need to incorporate the movement of the building occupants related to their characteristics (such as age, sex, abilities, etc.) as well as dimensional, structural and environmental factors.

Key Issues to consider

Safety and security precautions are not just a few applications that can be integrated after the construction of buildings. The following key issues has to be considered to enhance building design for extreme events.

Crowd dynamics

Crowd dynamics is the study of how, where and when crowds are formed and how they move. The behaviour of people may be affected by the conditions of their immediate environment as a result of interactions with the space and the behaviour of the other people. There may be spreading over the space in large environments and compression of groups of people in small spaces. The density of the surrounding crowd affects the speed of each person and individual behaviours due to personal characteristics and their response to environment can be included to modify the locomotion (Lo, et. al., 2002). Moreover, the behaviour of crowds show different characteristics compared to individual behaviours and the behaviour of people during disasters differs from that of normal conditions. People do not like interruptions and interference with their activities and lives, so they would follow routines and see warnings as an "exercise" ignoring the signs in order to continue with their normal behaviour when they faced with a disaster (Boer and Skjong, 2001). After an emergency alarm, occupants may perform various actions such as searching for something/someone around, warning other people, etc. before moving to escape routes. During unexpected events, the attention of people increases, however expectations can direct them to use less than the available information (Weick & Sutcliffe, 2001). Decisions by users of the space are based on their current knowledge which may be limited or incorrect.

Crowd management

Crowd management is the process of controlling the behaviours of large groups of people for their safety and security. It involves planning, organization, guidance and evaluation activities. Crowd safety and security in public areas are primarily the organiser's or operator's responsibility. A health and safety management system is required to monitor and control potential crowding risks in public areas. The four interacting elements that need to be considered to minimize injuries and death during crowd situations are defined as: time, space, information, and energy by Fruin (1984). He explained time as the crowding period; space as the size and layout of the occupied area; information as the perceptions of the people in the crowd to take some group action; and energy as the pressures created by the mass of people that can cause accidents and death. Within this context, crowd management considers the elements of events where crowds are involved dealing with the facility, size, behaviour of the crowd, means and routes of entrance and exits, communication, jamming and queuing. Another fact observed from the crowd incidents is that different types of crowds behave in different ways during disasters. It is essential to have information on different types of occupants (in terms of age, sex, abilities, etc.) to anticipate the problems. For instance, violent behaviours of fans can be a potential risk in sports venues, trying to evacuate people in a residential building during sleep time can slow down the rescue process.

Communication

The most important challenge for ensuring safety is to make building occupants aware of the impact of extreme events. Crowd related information involve various means of communication, any visual element and sounds that affect group perceptions, announcements, signs, trained actions of personnel, and even ticketing (Fruin, 1993). Considering the nature of the built environment and variety of characteristics of its occupants is essential in assigning the appropriate alarms system. Leckenby (2002) states two types of alarms: automatic or managed alarm systems, and sounder/bell/claxon alarms or voice-activated alarms within both types. Sound or voice alarm systems may need to be supported with visual alarms for people with hearing disability and visitors unfamiliar with the local language.

Way finding

The way finding ability of people varies with the visual cues received from the environment. Many physical and psychological factors influence perception in the environment such as the number of visual stimuli, the location, other occupants and the attentiveness of the occupants (Filippidis, et. al., 2006). Architectural elements and finishing tricks in use of colour, materials, barriers, extended/ freestanding walls/partitions as well as signs and graphical representations can be used to orient people by identifying and clarifying the type, location and routes for facilities and circulation visually. Consideration of way finding issues can highlight important clues about potential problems in space.

Identification of building design requirements

There is not a specific standard, guideline or code of practice for designing buildings to improve safety of people during disasters and emergencies related to crowd behaviour, movement or management. However, there are technical documents that focus on certain aspects of this context such as fire safety, accessibility or building safety (e.g. British

Standards (BS4422, BS5588 and BS8300), other technical documents published by BSI (PD 7974-6, DD 9999 and PAS 51), Approved Documents B, K and M, Green Building Guide: Safety at Sports Grounds and CIBSE Guide E: Fire Engineering). These documents usually characterize the circulation, exit flows and the types of exits regarding various rates for interior and exterior spaces, passages and circulation elements such as stairways, elevators, and escalators. The international standards and guidelines published by related organizations in other countries (e.g. International Organization for Standardization (ISO), National Fire Protection Association (NFPA), National Institute of Standards and Technology (NIST), Federal Emergency Management Agency (FEMA), Society of Fire Protection Engineers (SFPE)) also reflect their experiences and provide information and clues on safety design although there may be some conflicts in implementations, resources, management, etc. However, none of these technical documents can cope with every design problem efficiently because each building has its specific problems related to its unique characteristics. Crowd simulations can help in the development of new and improved codes and standards by assessing design solutions for current shortfalls and specifying generic design solutions. Data from buildings and the results of the applications of current codes and regulations can be used for computer modelling and simulation of people's movement in space (Fig. 1). The proposed design solutions would then be used to improve the current design procedures or to develop new standards for future building design and construction.

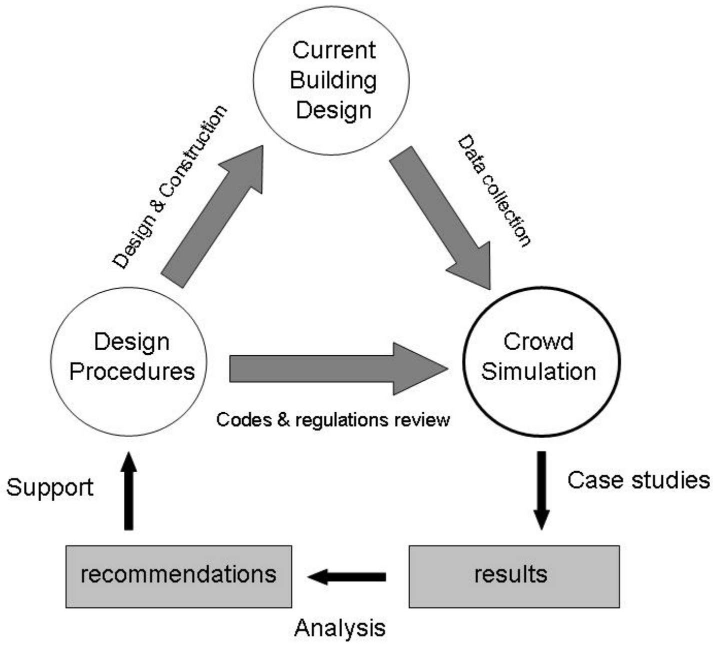

Fig. 1. Development of design solutions using crowd simulations

Basic building design requirements for safety and security

The interviews with the safety and security experts revealed that the measures for safety and security can differ in many ways. Furthermore, they can be conflicting which makes the building design problems more complex. For instance, access point provided by the security may not be suitable for the rescue personnel (Billington, et. al., 2002). Aesthetical or other building design aspects introduced by architects/ designers and security measures can also have conflicting aspects. For this reason, safety and security measures in buildings need to be studied in their own context for different types of disasters and emergencies and then compared to identify common risks and find alternative solutions for the conflicting issues. In general terms, safe and secure design of buildings is achieved with regard to consideration of the following main building design issues:

- Location of the building
- Size and capacity of the building
- Entrance to the building
- Building layout
- Characteristics of construction and finishing materials (e.g. flammability)

These issues need to be studied considering ingress and egress in detail to facilitate and enhance safety and security. The followings are the key factors for the design of ingress and egress routes and doors:

- Number of routes and doors
- Travel Distances
- Dimension of the routes and doors

Static data on these physical design requirements can be found in design standards and guidelines. However, architects and engineers have to keep in mind that ingress and egress design is highly influenced by the consequences of individual and group behaviours. This fact highlights the need to investigate the influence of behavioural factors on building design to enhance safety and security.

Exterior, Site and Immediate Environment

The design of the exterior façade, site and the immediate environment of the buildings have influence on access to the building, entrances to and exits from the building and circulation around the building. These requirements can be categorised into ; issues related to site and outdoor environment ; and issues related to façade design. Interviews with the National Counter Terrorism Security Office (NaCTSO) and British Transport Police (BTP) revealed that the design of the site and outdoor environment need to include *CCTV network* for monitoring, *sensors* for hazards detection, *alarm systems to warn building occupants*, *well-defined circulation and access routes*, effective *outdoor lighting*, border defining elements such as *railings, bars, gates, stall risers, bollards* for controlling the access and suitable *street furniture and accessories* (e.g. litter bins). The design elements that needs to be considered in Façade design are *security glass* that can resist high pressure, *mullions* to reinforce the glass, *internal and external grilles and roller shutters* to reinforce the glass surfaces *and façade materials*.

Interiors

Basic building design measures in building codes or standards can only give advise on minimum, maximum or average provisions. However, architects, designers and engineers have to make their own judgements on specific conditions such as disasters or smaller scale emergencies. The minimum design requirements to cope with the impacts of emergencies in all public buildings are *hazard detection systems* (e.g. fire detectors, CCTV monitoring), *alarm/warning system*, efficient *evacuation route and exit*, *escape lighting*, and *signage*.

Evacuating densely populated areas that are affected or in danger of being affected by a disaster is one of the critical problems to be investigated as part of research on mitigation activities. It is very important to ensure that the occupants are able to leave the building before the building becomes hazardous. The design of the spaces and circulation routes to emergency exits are dependent on the movement of large numbers of people at the same time. Chertkoff, et. al. (1996) claim that a stampede with injury and death do not always occur under time pressure. Special emphasis is required on some basic issues for effective evacuations: the position of exits and entrances, corridor patterns and widths, staircase locations and numbers (Billington, et. al., 2002). Arrangement of dispersed and equally balanced means of egress or ingress routes is vital for the occupants to be distributed within the space to avoid any crushing, bottleneck or queuing. Capacities, pressure and conflict points are needed to be defined for horizontal (e.g. corridors, paths) and vertical circulation routes (e.g. stairs, elevators, escalators, landings and lifts) and doors. Other building design issues that effect behaviours and movements of people can be summarised as:

- Building Geometry affects the occupation, circulation and the evacuation by enabling or preventing easy movement.
- Capacity of the space affects the degree of crowding (Fruin, 1993) and bottlenecks because as Casburn et. al. (2005) stated people spread out when there is enough space to avoid collisions and they bunch up without intersecting at bottlenecks.
- Occupancy levels are correlated with movement in entrance, exits and horizontal and vertical movement areas such as corridors, stairs, ramps, escalators, etc.
- Means of ingress characteristics related to speed and route effects the circulation and egress performance.
- Circulation routes and measures related to walking effects circulation and evacuation and provide key data on the movement and flow of people associated with distance and width data.
- Means of egress design need to consider travel distance, escape route capacities, movement characteristics, the relations with the subspaces of the building and design of the doorways to avoid bottlenecks during evacuation.
- Lighting is a vital design issue that assist circulation of people in the buildings in both everyday conditions and emergencies.
- Signage is essential in complex buildings to aid and reduce the time spent on way finding by providing options, and suggesting the best possible route for exit (Filippidis, et. al., 2006).
- Obstacles that can disturb the movement of people have to be avoided because they can influence the way the individual interacts with the space and other people around.
- Indoor emergency locations can be designed to provide safe areas for the occupants of the building and can facilitate the operations of rescue and health personnel.

Case studies

The purpose of the case studies was to identify the exit preferences of people and the factors effecting the exit choice in public buildings to enhance safety and security through building design for extreme events. Three public campus buildings were observed during the fire evacuation tests: a library, a fast food restaurant (EHB) and an open plan research hub.

Methodology

Evacuations from case study buildings were recorded using digital camcorders to observe people's behaviour, their exit preferences and identify bottlenecks. The number of people evacuated from the space were counted using tally counters. A questionnaire was distributed to evacuees after the evacuation tests to investigate the issues associated with the familiarity of people with the buildings, their exit choice, reasons for preferences and clarity of signs.

Findings

The distribution of the respondents in each space were observed by dividing the space into regions based on the geometry and the location of the emergency exits. The majority of the respondents indicated that they were familiar with the emergency exits in the buildings. More than 70% of the respondents stated that the emergency signs were clear enough to see and understand in all buildings. The fire marshals were present during the tests to reflect the situation that would occur in a real emergency cases. They did not have a role in exit preference but affected the pre-movement time. The results of the questionnaires indicate that most of the respondents did not face a bottleneck during the evacuation. However, bottlenecks were observed in two of the case study buildings on the video camera records. The most obvious bottlenecks were around the main exits.

One of the emergency exits in each building was the common door that is used as a main entrance and exit in normal use. Figure 2 illustrates the use of each exit in each building during the evacuations.

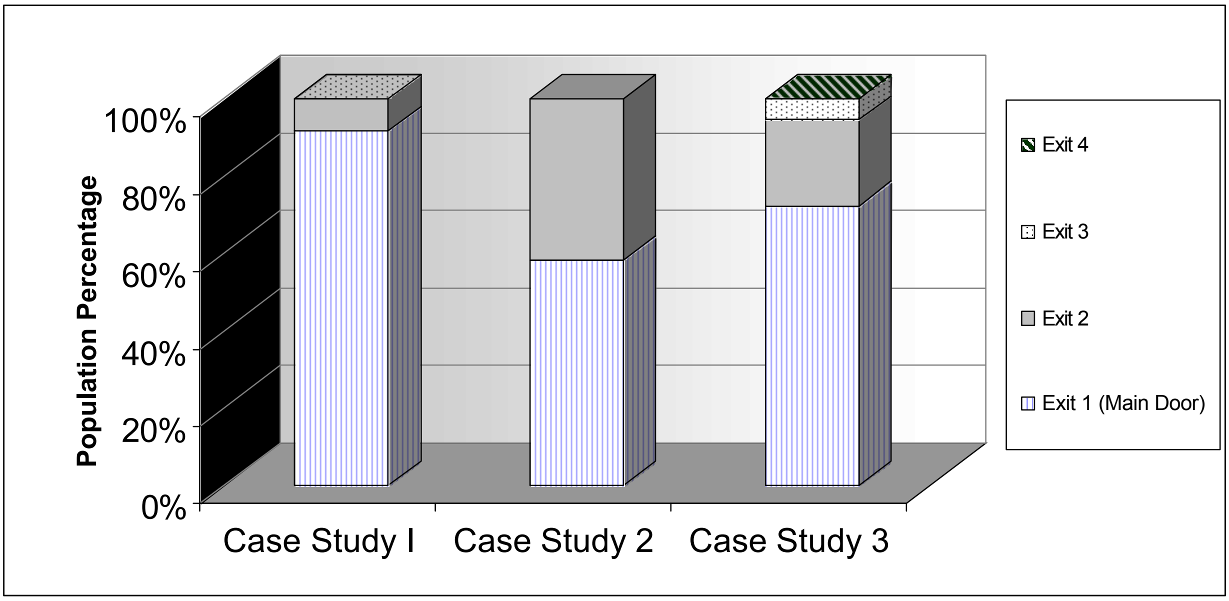

Figure 2 : Use of exits in each building

It is clear from the results of the questionnaire that the main doors are used more than the alternative emergency exit doors. Figure 3 illustrates the reasons for exit choices in each building.

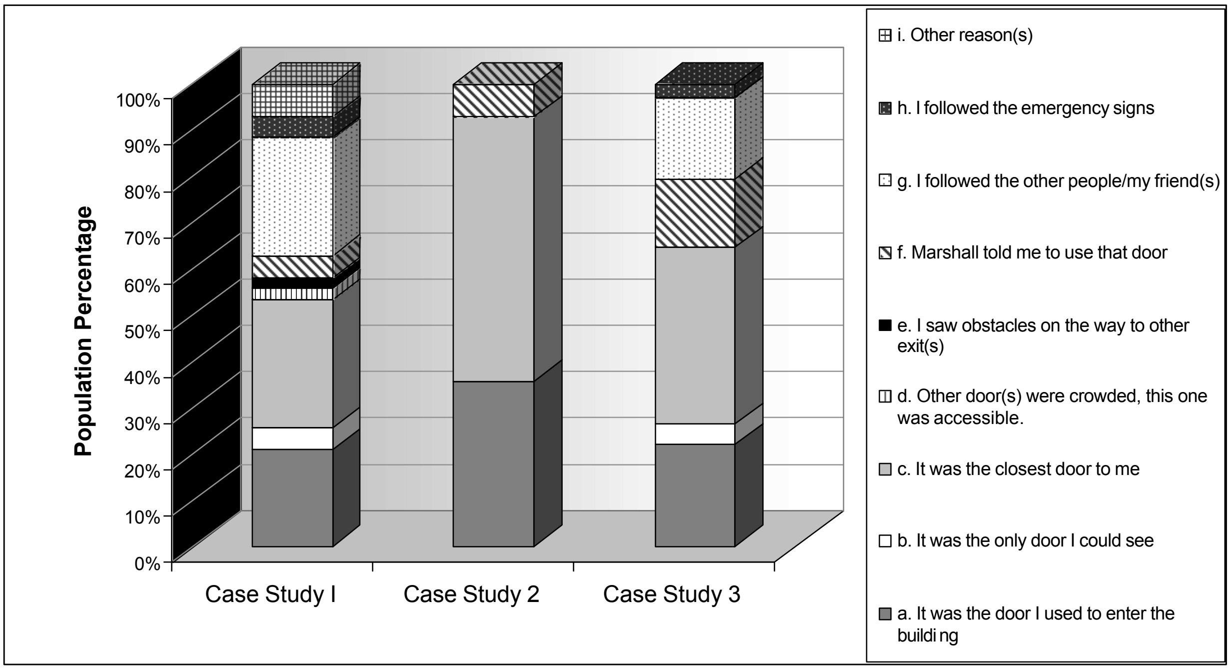

Figure 3: Reasons for exit preferences

The most common reasons to choose the main exits were closeness and familiarity for all the respondents. The secondary reasons varied for each case study. Other reasons given for choosing the main exit were being the first door coming to mind (which is a statement of familiarity), being the quickest choice, and being the door known leading to outside. This is also a statement of familiarity, knowing the end of the evacuation route.

This reason can also be true for a person unfamiliar with the building because the glazing usually used on the main doors offers a visual lead.

When the location of respondents and their responses are further analysed, the statements of being close to the doors they use is not true for all. The reason for some of the respondents to see the main entrance as the closest door may be due to unfamiliarity with other building exits or the lack of clarity of the exit signs. The main door may seem to be the closest because it is the most familiar and most used. Another reason may be because they did not act independently but followed or were oriented by other people (e.g. friends, marshals) and thought that it "must be the closest door" for them to leave the building from.

Conclusion

The mitigation activities for emergencies and disasters require a collaborative process and are not limited to response or recovery activities. The design of the built environment and its components including buildings, transportation routes and utility services need to be considered carefully to minimize the effects of disasters on people. It is important to consider crowd behaviour within this context as well as the nature of response and rescue operations for building design. Information on fire safety and some other generic building information for crowds can be found in some of the building standards, codes and guidelines but these can not cover all aspects of different building types and requirements because each building has its own unique characteristics and environmental constraints. Moreover, the static data found in these documents can limit or mislead the designer. There is a need to find a way to include the dynamic information associated with interaction of people with each other and with their immediate environment in the building design process and documents. In this way, the current building standards, codes and guidelines can be improved to enhance safety and security in the built environment.

In this context, this research highlights the issues associated with safety and security of people during disasters and emergencies. The aim is to develop a methodology to include dynamic building information. The focus is made on evacuation process, which is one of the most critical stages to consider and apply safety and security measures in the buildings. The case studies were conducted to observe the exit preferences of people in public buildings. Klupfel (2003) claimed that familiarity with the building or exits did not have a very important role in exit preference. On the contrary, in these case studies, the common reasons for exit preference are found to be related to being familiar and close to the exits. Although there was not a significant difference between familiarity and closeness, it is observed that people tend to use the familiar main exits more than the nearer exits. However, depending too much on familiar and nearest exits can prevent people to use alternative options during evacuation. Therefore, the design of buildings can be enhanced so that people are oriented to various evacuation routes and doors. In this way, bottlenecks can be avoided and the time for evacuation can be decreased, providing more time to save more people with less injuries caused by the impacts of the extreme event. Further steps of this research study will include a scenario-based study based on evacuation process using crowd modelling techniques.

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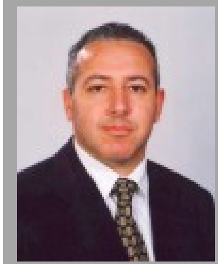

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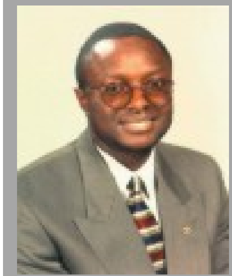

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