Evacuation from assembly halls containing loose and linked chairs

- *An experimental study*

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Abstract
The purpose of this report is to examine and analyze the difference in safety during evacuation with linked and unlinked chairs, respectively. In order to do this a series of experiments were concluded in a large assembly hall at Lund University. Three different setups were used in the experiments; one with a sturdy linkage, one with chairs linked together with cable ties and finally one setup with the chairs unlinked. The experiments were documented and the evacuees answered a questionnaire. The results were examined and analyzed in order to see if any conclusions could be drawn.

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Summary

The purpose of this report is to examine and analyze the different conditions during evacuation with linked and unlinked chairs, respectively. During temporary events such as theatrical plays, concerts and conferences, unlinked chairs are commonly used. In order to reduce the risks associated with evacuation, linked chairs could be an option. Investigations of hazards present during evacuations with unlinked chairs seem to be non-existent, thus there is a great need for research.

In order to examine the level of safety using linked chairs compared to unlinked chairs, a series of experiments were conducted in a large assembly hall at Lund University. The experiments were announced in advance and students from the Fire Protection Engineering programme participated. Chairs linked together using different linkage types were examined. The chairs were linked either with a sturdy linkage, with cable ties or with no linkage at all. The experiments were videotaped and each participant was given a questionnaire for further analysis.

Important aspects analyzed from the videotapes were the number of aisles that had been blocked, the number of rows which were still intact, the number of people who had to move a chair in order to continue their evacuation and the number of people who stumbled on a chair.

The answers from the questionnaires show that nearly half of the participants experienced the evacuation as faster when chairs were linked together, while half of the participants were unsure. More than one third had to move a chair in order to continue their evacuation during the experiments with unlinked chairs and two out of three participants experience the evacuation as safer using chairs that are linked together. The participants' own comments confirm that the possible risks of using unlinked chairs do in fact occur. The evacuations with unlinked chairs were experienced as more chaotic and more difficult because some of the evacuees moved chairs in order to evacuate creating an advantage for themselves but worsening the evacuation for others. Many of the participants were convinced that if it would have been a real scenario, the evacuation with unlinked chairs would have led to serious consequences.

A few rescue services in Sweden were given questions about their requirements and experiences concerning the use of unlinked chairs and chairs linked together in assembly halls. They agree on when linked chairs should be used, but they do not have any requirements on how they are to be linked together.

The experiments and the results show that using linked chairs instead of unlinked chairs provides a considerable safer evacuation. Using linked chairs should be required if they are to be used in assembly halls with a large seated audience. The experiments also show that the evacuation is safer using a more sturdy linkage, rather than connecting the chairs with cable ties. Consequently there should also be a requirement for using a sturdy linkage when connecting chairs.

Sammanfattning

Syftet med denna rapport är att undersöka skillnaden i utrymningsförhållanden med sammankopplade stolar och lösa stolar. Vid tillfälliga evenemang som teaterföreställningar, konserter, konferenser etc. används ofta lösa stolar. Det finns många risker i samband med utrymning med lösa stolar som skulle kunna minskas och/eller elimineras med stolarna sammankopplade. Idag finns inga föreskrifter i Sverige som säger att lösa stolar inte får användas vid större tillställningar i samlingslokaler. Undersökningar av risker vid utrymning med lösa stolar är tillsynes obefintliga och detta ger således ett stort behov för forskning i frågan.

För att undersöka hur säkerheten är med kopplade stolar jämfört med lösa stolar utfördes ett antal försök som ägde rum i en stor skrivlokal i Lunds Tekniska Högskola. Försöken var annonserade på förhand och studenter från brandingenjörsprogrammet medverkade. Totalt utfördes fyra utrymningsförsök med stolar sammankopplade med en fast länk, tre försök med lösa stolar och två försök med stolar sammankopplade med buntband. Försöken filmades och de deltagande tilldelades varsin enkät med frågor för vidare analys.

Från filmerna analyserades viktiga aspekter så som antalet gångvägar som blivit blockerade och antalet stolsrader som var intakta efter försöken. Även antalet personer som var tvungna att flytta på en stol för att kunna utrymma och antalet personer som snubblade på någon stol granskades.

Svaren på frågorna i enkäterna som deltagarna fick svara på visar att ungefär hälften av deltagarna upplevde utrymningen med stolar med en sammankoppling som snabbare, medan resterande hälften var osäkra. Mer än en tredjedel av deltagarna var någon gång tvungna till att flytta på en stol vid försöken med lösa stolar för att de skulle kunna utrymma, och två av tre deltagare upplevde utrymningen som säkrare med sammankopplade stolar. Deltagarna upplevde utrymningarna med lösa stolar som mer kaotiskt, som svårare på grund av att andra flyttade på stolar på så sätt att det gagnade dem själva men gjorde situation värre för andra. Många av deltagarna var även övertygade om att i en verklig situation hade försöken med lösa stolar fått allvarliga konsekvenser.

Ett antal räddningstjänster runt om i Sverige kontaktades och tillfrågades frågor kring deras krav, syn på och erfarenheter kring användandet av lösa och sammankopplade stolar i samlingslokaler. Där råder en enighet kring var gränsen går för när de ställer krav på att stolar ska kopplas samman. Däremot ställer de inga krav på hur de ska kopplas samman.

Försöken och deras resultat visar att utrymning med kopplade stolar är avsevärt säkrare än lösa stolar. Rimligtvis bör det ställas krav på att stolar ska vara sammankopplade med varandra om de ska användas i samlingslokaler. Försöken visar också att utrymningen är säkrare med stolar sammankopplade med en fast och orubblig sammankoppling än med buntband, och således bör krav finnas på att man ska använda en fast sammankoppling av stolar.

Contents

1 Introduction

This report is written as a degree project for the final course of the Fire Protection Engineering programme at Lund University, Sweden. The report deals with safety of evacuation in assembly halls with different types of linkage methods. Inspiration for the subject of this report was provided by Ackurat Industriplast AB.

1.1 Background

Assembly halls which do not contain fixed seats for a large audience are sometimes used in this field of application by setting up rows of simple chairs for the audience. These types of setups are commonly used for amateur or semi-amateur theaters, concerts, conferences, school plays etc. It is in the interest of those organizing the event to set up the chairs so that they form beautiful straight rows that make them easily accessible for the audience. In case of a fire it is in the interest of everyone that the chairs do not block the escape routes, thereby trapping people inside the building. Therefore the chairs are often linked together to provide a sturdier setup. But fire safety is not always in the front of the mind of someone setting up a play and so a simpler, cheaper and less sturdy method of linking the chairs together is often preferred. Swedish law states that it is the owners of, or the owners of rights to use, the building that are responsible for the fire and evacuation safety. But since the law is a framework law it does not leave any clues as of how to achieve the required level of safety. This means that the local authorities, i.e. the rescue services, need to make requirements on how to implement the laws regulating fire safety. However, some local authorities only require that the chairs need to be linked together and there are no requirements about *how* they are to be linked together. Since those who set up the chairs often choose the simplest solution, cable ties are commonly used for linking the chairs together. The level of safety when using cable ties and other less sturdy linkage methods can be questioned because a less sturdy setup may not live up to the otherwise strict demands on the level of safety concerning fires and evacuation.

1.2 Purpose

The purpose of this project is to evaluate different methods of setting up and linking chairs together in straight rows, from the aspect of evacuation safety. Specifically, one setup with a very sturdy linkage method will be compared to a less sturdy linkage method, and one setup with unlinked chairs. Possible problems with each type of setup will be identified, and as much as possible, quantified.

1.3 Methodology

A literature study was performed to find out if previous research has been made about linked chairs. No former research was found and so the search was broadened to include evacuation of assembly halls in general and especially evacuation affected by loose objects. Laws and regulations concerning fire and evacuation safety in assembly halls were also studied and interviews with rescue services were performed. By studying which factors that are most important in regard to evacuation of assembly halls and which laws and rules apply, ideas on how to perform the experiments to evaluate the different linkage methods were created. Evacuation experiments of a rather large scale were planned and carried out. Finally, the results were analyzed by viewing video recordings of different angles of the experiments, and also by analyzing questionnaires answered by the participants from the experiments.

1.4 Limitations

The evacuation experiments did not take time of recognition nor time of response in consideration; the only aspect of evacuation the experiments included were the time of travel (for information of the stages of evacuation, see Chapter 2.3). The experiments were performed without smoke, thereby offering perfect visibility. Only one layout of the number of chairs, and their position, was used. No disabled persons participated in the experiments.

2 General description of evacuation

A person must be able to evacuate from a building in a satisfying way in case there is a fire. This means that the building must be designed and have arrangements and devices that will make the evacuation easier. A fundamental requirement is that the building has escape routes that will lead the evacuees out from the building. The escape route must be safe and available, which then leads to certain demands on the ability to move forward in the escape route (Brandskyddshandboken, 2005).

There is a big difference in the ability to evacuate between different persons in a building. However, there is little information about how a building should be designed so that all kinds of person's requirements are met, for instance disabled people (Brandskyddshandboken, 2005).

2.1 Behavior during evacuations

There are several factors which affect the course of an evacuation e.g. the way a person experiences the prevailing situation and how a person chooses to take action.

On numerous occasions when a fire has occurred, the fire investigations have shown that during the evacuations, the persons were helping each other a lot. Those who were not familiar with each other prior to the evacuation hesitated for a while before they took measures. But once they did, they tended to create smaller groups and evacuated together. This kind of behavior is very common at larger premises with many people, such as theatres and cinemas, where the persons are not familiar with each other and where everybody has a clear view over the crowd (Frantzich, 2001).

Panic can be the cause of death during fires, although it rarely occurs. The phenomenon can be described as if a person's actions would cause any harm to someone else. There might be a possibility for panic to occur if the persons, who are evacuating out of a building, are experiencing that their possibilities for quickly getting out are decreased and at the same time the fire is increasing in strength. The whole course is associated with strong feelings of anxiety and fear. A single person, who has been stricken by panic, can pass on the feeling of panic and thereby causing mass panic (Sime, 1980).

2.2 Factors affecting evacuation

Different factors have different kinds of influence on an evacuation. These factors affect the way humans behave during a fire and evacuation, and also their ability to evacuate. These factors can preferably be divided into three categories (Frantzich, 2001):

- Factors which are dependent on the humans in the building
- Factors which are dependent on the building itself
- Factors which are dependent on the fire

2.2.1 Factors dependent on the humans

Number of people and their distribution
The number of people who are present in a building and their distribution throughout the building both have a substantial influence on the time of evacuation. If a large number of people use the same exit, then a queue might occur.

Ability to move
The ability to move to a safe area may vary from person to person. An increasing number of people in a building will lead to a decreased pace of walk. People who in some way are restrained from evacuating, i.e. disabled persons or children, can have a negative effect on the pace of walk of others in a building, who might be prevented from walking past the restrained person. Reduced visibility also affects the ability to evacuate quickly.

Social connections
A person's behavior is very much dependent on whether he or she is alone or not. Evacuation is usually carried out in groups, especially if the persons are familiar with each other. In big assemblies, such as theaters, it can take quite a long time before someone chooses to take action because people do not want to look foolish by taking the first step.

Role and responsibility
Leadership is something that can make an evacuation go much faster, since the risk of someone not willing to take action is decreased or even eliminated.

Motivation
Prior to an evacuation, the evacuees are usually busy with something, like watching a play, shopping, eating in a restaurant and so on. The persons may not want to start an evacuation, but instead rather continue with their ongoing activity. And so the persons may not start evacuating unless they do not see the fire itself with their own eyes.

Directed and specific attention
Persons at a theater are usually focused towards the scene and they do not expect a fire alarm from somewhere else. The persons can be completely unaware of what is going on somewhere nearby.

Awareness of the building
People in familiar environments will have an easier task of evacuating to a safe place. This is due to the fact that the time for a person's decision making and reaction is shortened because there will be less uncertainty concerning making a choice of where to evacuate. People in unknown environments will usually use the same way and same exit for evacuation as they used when they got in to the building. This phenomenon can also occur in familiar environments, but not in the same extent as if it were in unknown environments.

Influence of smoke
If the evacuating people are exposed to smoke their ability to move and make decisions is complicated. As already mentioned, reduced visibility will reduce the ability of an effective evacuation and at the same time, toxic gases will make the time needed for a person's decision making and reaction longer (Frantzich, 2001).

2.2.2 Factors dependent on the building

Ability to orientate
In complex buildings with escape routes not changing direction with a 90 degree angle, it can be more difficult to orientate. This could have the consequence of making it more difficult to find an exit, if the building is unfamiliar. Difficulties with seeing other exits, persons and the fire can also increase the time of evacuation.

Layout of escape routes
Doors leading to escape routes should not look like other doors. They should be different in color and shape for instance. I buildings such as cinemas and theaters, the working staff should open up the doors and thereby make it easier for the evacuees to evacuate.

Location of escape routes
Evacuation ways should be positioned in a way which will make it appear natural for the evacuees to use in their evacuation during the present activity, such as in cinemas and theatres (Frantzich, 2001).

2.2.3 Other factors
Besides the already mentioned factors affecting evacuation, other factors are the lighting, fire alarms and guiding evacuation signs (Frantzich, 2001).

2.3 Modeling evacuation and escape time
The time required for safely evacuating can be modeled in different ways. Evacuation can also be explained and modeled by splitting it up into different stages. The figure below shows a simplified model of the complete required safe escape time.

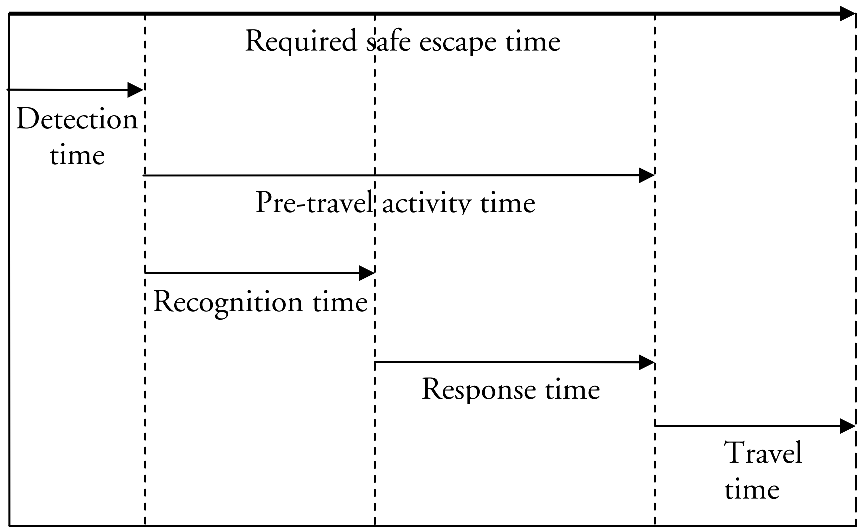

***Figure 2.1** - Simplified model of an evacuation*

The required time for safely escaping is defined as the sum of the time of detection, recognition, response and travel. The first part of the evacuation time consists of the pre-travel activity time, the other part consists of the travel time. The pre-travel activity time is defined as the sum of the recognition and response time. A general formula for the total amount of time for an evacuation will then be as follows:

$$t_{evacuation} = t_{detection} + t_{recognition} + t_{response} + t_{travel}$$

2.3.1 Detection time

Detection time is defined as the time from which the fire starts until it is detected by either a system or a person (ISO 16738). A system can be a smoke detector which then sends a signal to sound the alarm. If a person detects the fire he can then alert others by telling them in person, or if possible, manually start the fire alarm.

2.3.2 Recognition time

Recognition time is defined as the time from the moment at which a warning of the fire is given, to the moment when a person first responds to the warning (ISO 16738). There are numerous ways in which a person can be given a warning, such as a fire alarm, information from others persons, smoke or just by seeing the fire itself. Depending on the location of the fire, the time of recognition can vary greatly (Frantzich, 2001).

2.3.3 Response time

Response time is defined as the time from the moment when a person has understood that there is a danger, to the moment where he/she takes action (ISO 16738). This may be starting the evacuation, trying to put out the fire or informing others. The time of response is the part which is the most difficult to determine (Frantzich, 2001).

2.3.4 Travel time

Travel time is defined as the time which has passed from the moment movement towards an exit has begun to the moment when the evacuee has reached a safe location (ISO 16738).

3 Evacuation of assembly halls

An assembly hall is defined by the Swedish Board of Housing, Building and Planning (the Swedish authority regulating building code etc), as every hall or group of halls within a fire compartment, where a relatively large amount of people with poor knowledge about the hall can reside. An assembly hall is expected to be able to hold more than 150 people. It is supposed to be used as a lecture hall, cinema, church, restaurant, theater etc (BBR, 2006). Usually, people in assembly halls do not have much knowledge about the escape routes. This means that the demands on assembly halls concerning the safety of an evacuation are much more strict than usual.

When it comes to assembly halls, there are several problems that may occur. One is that there might be more people than allowed, which is not that uncommon (Eksborg et al, 2001). Obviously, this will make the evacuation take longer time. Mass panic is another problem that can occur in assembly halls, however it rarely happens. This was the case in the Gothenburg fire in 1998 (see Chapter 3.1.1). In cases of fires in assembly halls resulting in many deaths, such as in Gothenburg, the fire investigations often have many mutual conclusions. Some of these state that it is important to:

- Discover the fire and take action at an early stage.
- Improve the ability to orientate to and through the escape routes.
- Make sure that the number of people does not exceed the capacity of the escape routes and make sure that they do not become blocked.
- Educate the staff to make sure that they know which actions to take in case of a fire.
- Reduce the risk of a fast course of fire by limiting the amount of combustible furnishing.

3.1 Former research

A literature study was performed to find out what former research has been made about evacuation of assembly halls, with or without loose objects. Google was used to search the Internet in general and library databases as well as engineering databases were used to get as much information as possible. The following databases were used:

- Electronic Library Information Navigator (ELIN)
- Lund University Library's search engine (Lovisa)
- Compendex
- Civil Engineering Database (CEDB)
- EEVL - Engineering section
- ENGnetBASE CRC
- ICONDA

The following search words were used, by itself or in combination with other words: evacuation, egress, assembly, assembly hall, assembly occupancy, assembly occupancies, linked chairs, loose chairs, loose objects, loose furniture. The search was performed in English, and when applicable also in Swedish.

The literature study turned out many references to evacuation of public buildings and assembly halls. Studies investigating different types of fire alarms' effect on the response time are very common. Comparisons between travel times in experiments and travel times calculated by simulation software are also common. However, only one reference to loose objects affecting evacuation was found; in investigations of the Dance Hall Fire in Gothenburg. No studies were found concerning the effect of loose or linked chairs during an evacuation.

3.1.1 The dance hall fire in Gothenburg

In 1998 a fire claiming 63 lives occurred in a dance hall in Gothenburg. The fire had started in an adjacent room, which was also one of the two exits, and after a while a door into the dance hall had been opened leading to a rapid fire progress. The hall was approved for 150 persons but as many as 380 persons were inside when the evacuation started (Eksborg et al, 2001). Investigations following the fire showed that the main problems were:

- Overcrowding in relation to the number of emergency exits and their dimensions
- Lack of fire alarm
- Combustible storage in an emergency exit (Comeau & Duval, 2000)

The investigations also showed that loose furniture, a ticket table situated very close to the only available exit, possibly delayed the total time of evacuation by up to 15 %. The ticket table's original position is known but it remains unclear how it was moved during the evacuation, and how much it affected the egress (Eksborg et al, 2001).

3.2 The effect of loose objects on evacuation

Since so little is known about the possible risks of loose objects during an evacuation further studies were deemed necessary. The type of loose objects considered, by the authors of this report, to be most appropriate to study are temporary setups of chairs. The reasons are that loose chairs are not only commonly used, but more importantly there are many of them, usually covering most of the room they are in. These types of setups are typically used in assembly halls not originally designed for, but temporarily used, for an activity involving a seated audience. Such activities can be amateur or semi-amateur theatrical performances, concerts, conferences, school plays etc, where chairs are simply brought into the assembly hall and put into straight lines. The authorities regulating fire safety often require that chairs set up this way are linked together. However, there are no requirements on how the chairs are to be linked together, often leading to the use of questionable linking methods like cable-ties or even adhesive tape. Another possibility is that whether the chairs are linked or not might make so little difference during an evacuation that it is negligible.

A European standard for testing the performance of the links used to secure chairs together exists. The standard contains tests where a row of linked chairs is applied a force in order to see how much the row is displaced. The main problem with this standard is that it holds no legal authority. It may also hold little or no relevance to evacuation since its development has not been based on a scientific approach on evacuation. Furthermore, the tests used in this standard are dependent on which models of chairs are used; leaving the type of chairs used a variable. This means that one type of linkage can be approved of by the standards institute and still not perform well enough when used with different models of chairs than tested with at the institute (SS-EN 14703:2007).

Different kinds of courses of fires and evacuations are essentially infinite, and loose objects have been shown to be a problem in a previous case (the Gothenburg fire). Therefore it is not unreasonable to question the safety of an evacuation when loose chairs are used, or the need for a more reliable sturdy linkage method. Consequently, the authors decided to evaluate if linkage of chairs really is needed from an evacuation point of view, and if so, if the level of sturdiness of the linkage affects the safety of an evacuation.

4 Current laws and guidelines in Sweden regarding loose chairs in assembly halls

This chapter presents the Swedish laws, decrees and regulations applicable to fire safety and evacuation of assembly halls containing temporary setups of loose or linked chairs. Although generic advice and guidelines have no legal authority, they too were examined to find out what they state regarding this subject.

4.1 Laws

The current Swedish laws regulating accidents regarding human life and health is *The law of protection against accidents* (Lagen om skydd mot olyckor, SFS 2003:778), with its decree: *Decree of protection against accidents* (Förordning om skydd mot olyckor, SFS 2003:789). They are framework laws leaving plenty of power of its implementation to subordinate authorities and organizations. When it comes to human safety in case of a fire it states:

> "*Owners of, or owners of right to use, buildings or other facilities shall in legislative extent provide equipment for firefighting and lifesaving in case of fire or other accidents and otherwise institute actions required for preventing fire and preventing or limiting injuries in consequence of a fire."* (Lagen om skydd mot olyckor, SFS 2003:778)

Since it is a framework law it does not state any specific requirements for evacuation of assembly halls, thus there are no references to loose chairs either. The law does not specify what actions needed to be taken in order to *prevent fire and preventing or limiting injuries in consequence of a fire*. That leaves the interpretation and implementation of the law to the local authority that enforces it; in this case the rescue services in the particular municipality.

New buildings, or buildings being modified, fall under the law of *technical requirements of structures etc* (Lag om tekniska egenskapskrav på byggnadsverk, m.m., SFS 1994:847) with its decree with the same name (Förordning om tekniska egenskapskrav på byggnadsverk, m.m., SFS 1994:1215). This law and decree state that structures shall provide the persons inside a way to exit the building or to be otherwise saved, in case of a fire. However, these laws only regulate the building itself and not its loose objects, thereby making it ineffective when considering setups of loose chairs.

4.2 Generic advice

Generic advice, such as guidelines and handbooks, are published by various organizations in order to clarify how to meet the requirements in the laws and regulations in a practical way. These handbooks have no legal authority, but they do provide information on good practice. One of the most comprehensive and most commonly used handbooks is *Brandskyddshandboken* (Brandskyddshandboken, 2005). In regard to assembly halls and loose chairs *Brandskyddshandboken* states that:

- The seats in an assembly hall should be set up in straight rows or in one or more fields of benches, so that an evacuation can proceed easily.
- Rows of benches should not contain more than 40 seats if there are two ways to exit the row. Otherwise, the rows should not contain more than 10 seats.
- The distance from one row of seats to the row in front, must be at least 0.45 m.

- Aisles between two rows of seats shall be at least 1.0 m wide (Brandskyddshandboken, 2005).

4.3 The rescue services' interpretation of the law

The only laws that can be practically considered to apply to loose chairs in assembly halls are the law and decree *of protection against accidents*. Although they do not state any specific requirements regarding loose chairs, their framework quality allows the enforcing authority to interpret what they consider to be in accordance with the law.

To find out what requirements the enforcing authority, in this case the Swedish rescue services, have concerning loose chairs in assembly halls, a number of rescue services were contacted. Since each local rescue service has local authority, four different rescue services in Sweden were contacted to see if their requirements differed. The selection of which rescue services to interview was based on location, to include major cities ranging from northern to southern Sweden. One fire safety engineer or leading fireman from each location was asked the following questions:

1. Is there a limit to the number of chairs, after which you require them to be linked together at temporary arrangements such as theaters, concerts etc?
2. If you do require them to be linked together, do you have any requirements of how to link them?
3. Do you know about any situation where loose chairs have caused problems during an evacuation?

Answers from Region South Fire and Rescue Service (Texell, 2007):

1. Loose chairs for more than 50 people are required to be linked together at least five by five.
2. There are no requirements on how to link the chairs together.
3. No

Answers from Gothenburg Fire Brigade (Rystedt, 2007):

1. Loose chairs for more than 50 people are required to be linked together.
2. There are no requirements on how to link the chairs together.
3. No

Answers from Stockholm Fire Department (Blomqvist, 2007):

1. They have a recommendation that loose chairs for more than 50 people are required to be linked together at least five by five.
2. There are no requirements on how to link the chairs together.
3. Probably, but nothing has been documented.

Answers from Umeå Fire Department (Samuelsson, 2007):

1. Based from case to case, but usually when the number of chairs exceeds about 30 chairs we require them to be linked together. But it might as well be ten chairs; it depends on their location in the building and how close they are to the exits.
2. There are no requirements on how to link the chairs together.
3. No

4.4 Practical utilization

Ultimately it is the owners of, or the owners of rights to use, the buildings that are responsible for the fire and evacuation safety. The rescue services is the enforcing authority that help the owners by clarifying what is in accordance with the laws and regulations, and if needed can set fines or even prohibit the utilization of the building if the laws are not followed. This leaves the owners with the task of setting up chairs for the audience that are safe in case of a fire. However, the question remains how the chairs are supposed to be set up in order to be safe enough. The approach deemed most suitable to answer this question was a large scale experimental study. The authors decided to perform evacuation experiments with the purpose of finding advantages and drawbacks with different kinds of temporary setups of chairs, and to suggest if there is a need for legislative requirements on temporary linkage of chairs.

5 Evacuation experiment

Evacuation experiments of a rather large scale were chosen as method of evaluating the possible risks of temporary setups of loose chairs. The purpose of the experiments was to see if chairs linked together provide a safer evacuation than unlinked chairs, and if a sturdy linkage method offers a significant improvement over a less sturdy one. Three setups were to be tested:

- One setup with unlinked chairs to be used as a reference point.
- One setup with chairs linked to one another with cable ties to represent the less sturdy linkage method.
- One setup with chairs linked together with a sturdy linkage.

In order to create realistic conditions the authors decided that at least 80 people were needed to achieve a high enough level of crowding. In the continuation of this chapter the way the experiments were prepared, executed and documented will be presented.

5.1 Experimental setup

The experiment was performed in a large examination hall at Lund University. It suited the authors purpose well because of its large open areas and abundance of appropriate chairs. To be able to execute the experiments as efficiently as possible, two identical setups were created at the short sides of the hall. Each setup consisted of 80 chairs divided in two sections with a aisle in between. Each section was made up of four rows with ten chairs in each row. To create as much crowding as possible in the experiments, the shortest distances allowed according to guidelines were used (Brandskyddshandboken, 2005). The distance between the front of the chairs in one row and the back of the chairs in the row in front was 0.45 m. The free width of the aisle was 1.0 m. To close off the area to ensure that the test persons evacuated through an imagined door measuring 0.9 m, tables were used as obstructions. A schematic of the setup can be seen in Figures 5.1, 5.2 and 5.3.

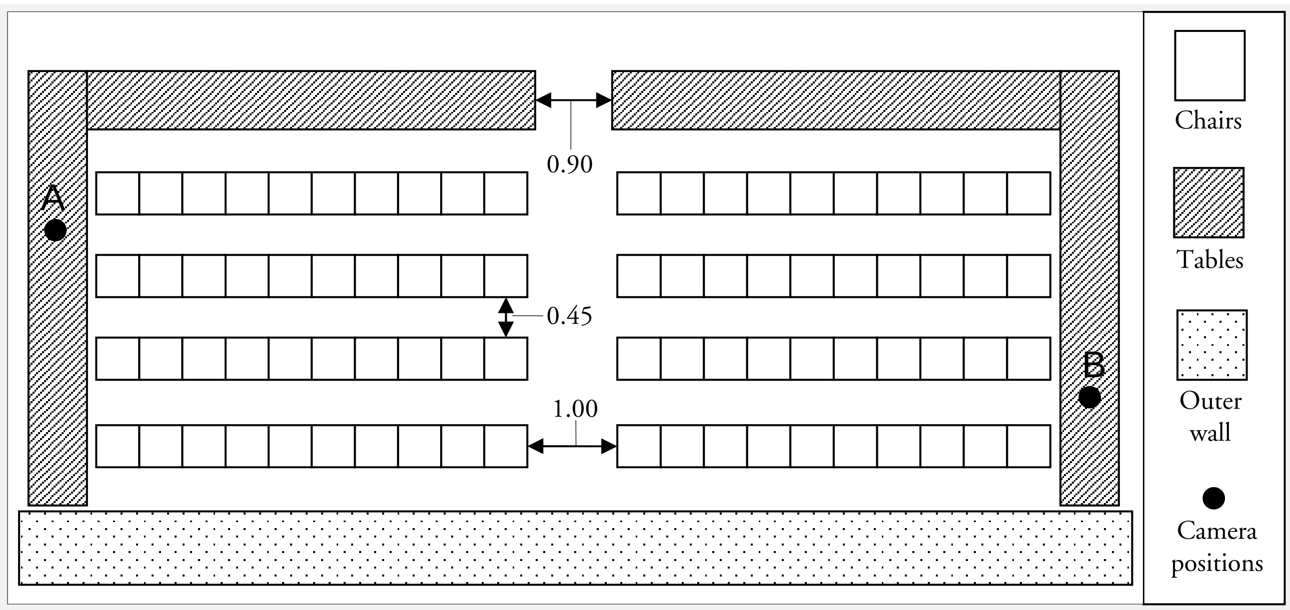

Figure 5.1 *- Schematic of the experimental setup, measurements in meters*

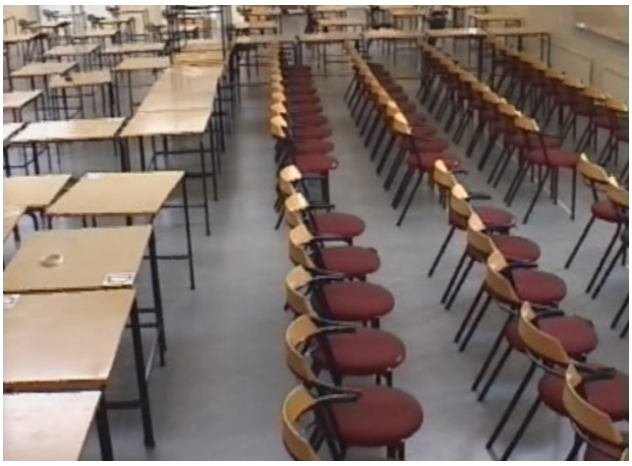

Figure 5.2 *- Setup as seen from video camera A*

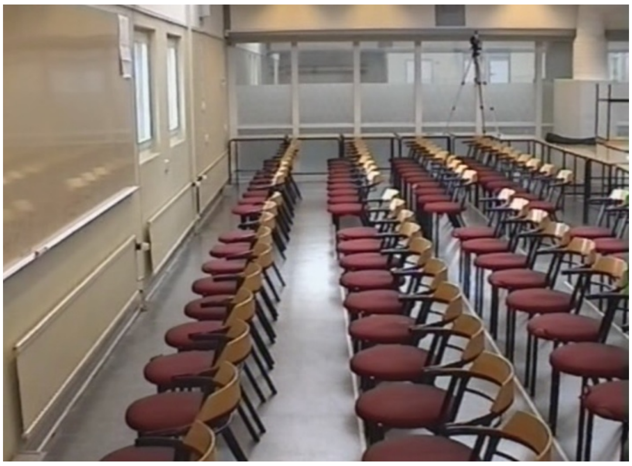

Figure 5.3 *- Setup as seen from video camera B*

5.1.1 Linkage methods

Three different methods of linking the chairs together were used:

- **Sturdy linkage** – The sturdy linkage was accomplished by a long wooden spar attached to the back of a row of chairs using cable ties. The wooden spars used were long enough to tie all ten chairs in the row to the same spar. Each chair was connected to the spar with two cable ties, one at each back leg. The linkage method is shown in Figure 5.4.

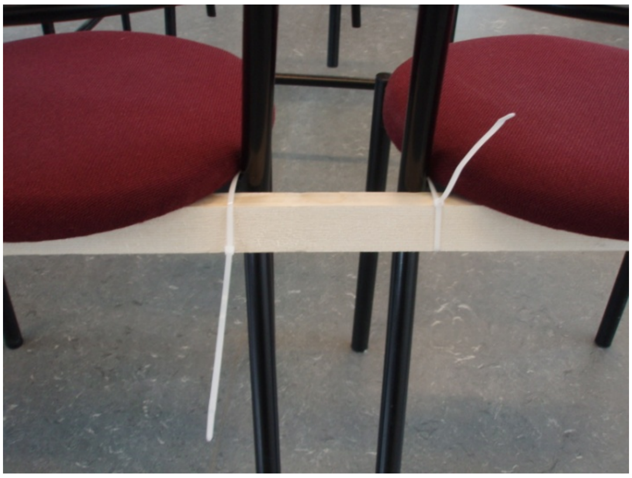

Figure 5.4 *- The sturdy linkage type*

- **Cable ties** – The chairs were connected to each other using cable ties on both the front and back legs. The linkage method is shown in Figure 5.5. The chairs used in these experiments were less than ideal for cable tie linkage because of their armrests. To make up for this the cable ties were tightened very hard in order to wedge the chairs firmly against their armrests. This linkage method proved to be less robust than the sturdy linkage method, but still a lot more robust than loose chairs.

Figure 5.5 *- Chairs connected using cable ties*

- **No linkage** – The chairs were put in a row with nothing connecting them to the chair next to it. Setup is shown in Figure 5.6.

Figure 5.6 *- Chairs without linkage*

5.1.2 Chairs used in the experiments

The chairs used in the experiments were a simple type with a steel frame, a wooden back support and a cushioned seat. Figure 5.7 shows a simplified schematic of the chairs and how the rows distanced.

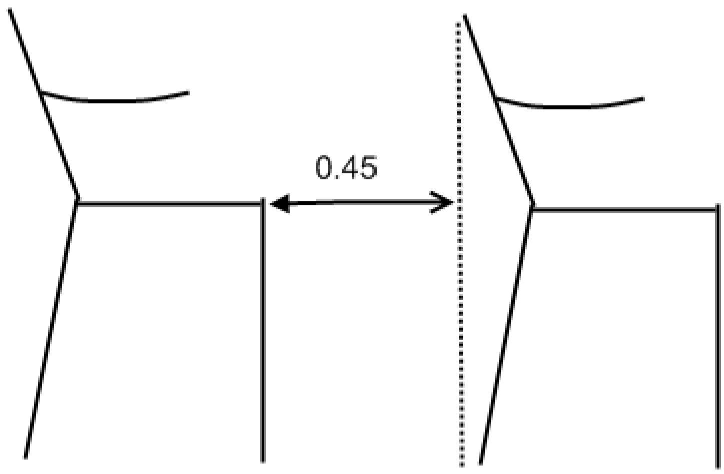

Figure 5.7 *- Schematic of the chairs and the distance between rows*

5.2 Participating evacuees

There were 91 evacuees participating in the experiments. All of them were students of the Fire Protection Engineering programme at Lund University, and most of them (~70 %) were first-year or second-year students. The evacuees ranged from about 20-35 years old and none of them were disabled. They wore no outer clothes or bags during the experiments. The test persons were not told the reason of this study before the experiments. They did not know that different types of linkage methods would be used as well. They only knew they were participating in an evacuation experiment.

5.3 Documentation

Two video cameras in each experiment were used to document the experiments. Camera A was located at one side of the setup in level with the aisle between the third and the fourth row as seen from the wall. Camera B was located between the first and the second row. Both cameras were placed on tripods to get a good view of the experiments. See Figure 5.1 for camera locations and Figure 5.2 and Figure 5.3 for an example of the camera view.

After the experiments, the test persons got informed of the reason of this study and the different linkage types used. They then got to answer a questionnaire, see Appendix A, to give their opinion on the experiments and to assess which setup they believed to be the safest one. The participants got to answer the following questions:

- In which setup did you experience the evacuation as the fastest one?
- Did you notice any essential difference between the setups?

  If you answered yes, what was the difference?
- Were you ever forced to move one or several chairs in order to proceed with the evacuation?
- Did you experience the evacuation as safer when the chairs were linked?
- Other comments?

5.4 Implementation

The experiments were carried out on Wednesday the 26th of September 2007 between 12:00 and 12:45. Time was limited since the experiments had to take place during a lunch break in order to get a hold of enough number of test persons. The authors of this report directed the experiments and were assisted in setting up the experimental areas by one assistant. When the test persons arrived they were greeted and asked to leave their outer clothes and bags and take a seat in the first test setup. When everyone had arrived, the authors of this report explained that when a signal was given the evacuees would evacuate the test area as fast as possible through the middle aisle and out the exit. To further motivate the evacuees to hurry out of the area they were asked to see themselves as in a situation where there was a fire in the hall they were sitting in. The evacuees were also told to swap positions between the tests and not to sit next to the same persons they did in the former tests. This was done in order to reduce learning effects i.e. to prevent the test persons from changing their behavior from one test to another. Since the experimental setup consisted of 80 chairs and 91 test persons showed up, the authors were able to alternate some evacuees from one test to the next. This was believed to further reduce learning effects.

5.4.1 Order of experiments

The two experimental setups were initially set up with sturdy and cable tie linkage respectively. Two setups were used to be able to run as many tests as possible in the limited time period. This way the evacuees could evacuate one test setup and move directly to take a seat in the next. While they were making their way to the next setup, the one just being used was restored. The experiments were performed in the order shown in Table 5.1. A total of nine experiments were run; four with sturdy linkage, two with cable ties and three with no linkage at all. The reason for running four tests with sturdy links and only two with cable ties is because of the time limit and the use of two test setups.

Experiment nr	Linkage type
1	Sturdy
2	Cable tie
3	Sturdy
4	Cable tie
5	Sturdy
6	No linkage
7	Sturdy
8	No linkage
9	No linkage

Table 5.1 *- The order of which the experiments were carried out*

5.4.2 Experimental manipulation

To better see what potential dangers might arise and possible strengths and weaknesses with each linking type, two of the test persons were given special instructions. Their instructions were to give the chair in front of them a good push at the very start of each test and then act as everyone else and make their way out. If they were in the first row and had no chair in front of them they were to push their own chair backwards. Specific instructions were given in order for the moles to use the same amount of force in every experiment, with no regard to the result of the push. These two *moles* were present in every experiment.

6 Results

In the following sections the results from the evacuation experiments and the questionnaires will be presented respectively. The experiments will be evaluated from quantitative aspects as well as qualitative observations during the evacuations.

6.1 General description of the evacuation

The evacuees were sitting down; talking to each other when the signal to start the evacuation was given. Because the evacuees were given instructions on what the signal meant and what to do once it sounded, the recognition and response time can be disregarded; the evacuation started immediately after the signal. The following course of events is best described with the aid of screenshots from the video cameras, see Figure 6.1 to 6.6. Screenshots are from the fifth experiment and the linkage used is the sturdy one.

Figure 6.1 - Before start signal was given

Figure 6.2 - 2 seconds after start signal

Figure 6.3 - 10 seconds after start signal

Figure 6.4 - 20 seconds after start signal

Figure 6.5 - 30 seconds after start signal

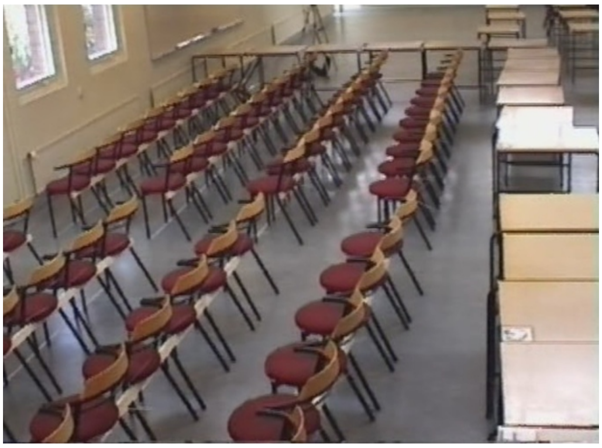

Figure 6.6 - Setup after the experiment

The course of events was similar in all experiments; the evacuees rose from the chairs when the signal was given and started to move towards the center aisle and out through the exit. People typically waited in line when they were hindered by people in from of them, although there were quite a bit of crowding and pushing; the closer to the exit the more crowding and pushing. A few people stepped over the rows of chairs, or pushed chairs apart in the setup with unlinked chairs, in order to get ahead in the queue. The differences in affecting the egress by the various linkage methods will be closer examined and presented in Chapter 6.2. More screenshots are available in Appendix B.

The two *moles* present in the experiments had little effect on the evacuation, even though their ability to manipulate the chairs differed between the linkage methods. In the experiments with the sturdy linkage the moles did not move the chairs more than a few centimetres; the affected row remained perfectly straight and unblocked. When the cable ties were used the moles pushed the chairs between 10 and 20 centimetres, taking the chairs next to the one pushed with it for about half that distance. These chairs jutted out from the row making them an obstacle. In the experiments with unlinked chairs the moles pushed the chair until it was stopped by coming in contact with a person in the next row, usually after around 15 to 20 centimetres and thereby becoming an obstruction. When an unlinked chair was pushed backwards it toppled, obstructing most of the aisle.

6.2 Quantitative results from the evacuation experiments

The evacuation experiments were evaluated using the recordings from the video cameras. Each experiment was viewed several times from both camera angles. In order to quantify the results several aspects were selected to be documented. The aspects were as follows:

- **Number of aisles that have been blocked –** Rows of chairs with one or several chairs moved into the aisle itself, thereby blocking it. The aisle was defined as blocked if the width of the aisle was clearly less than 45 cm.
- **Number of disturbed rows of chairs with the aisle still unblocked –** Rows who after the experiment were not in their original position but still allowed evacuation through them.
- **Number of rows of chairs still intact –** Rows still in their original position after the evacuation.
- **Number of people needing to move a chair in order to evacuate –** People who had to move a chair in front of them because the aisle had been blocked or disturbed. People who crossed rows by moving chairs are not accounted for in this category.
- **Number of single chairs moved out of position –** Chairs who were not in their original position after the experiment.
- **Number of people stumbling or getting caught up on chairs**
- **Total time of evacuation –** The time from the signal was given until the last person had left all chairs behind.
- **Number of people using chairs as support –** People who clearly had to support themselves by grabbing chairs in order to keep balance.
- **Number of people crossing rows –** Persons belonging to this category were those who jumped over one or several rows and those who moved one or several chairs in order to cross rows.

6.2.1 Tables and diagrams of the results

The following table and diagrams presents the average values from the different experimental setups. Table 6.1 shows the absolute averaged values of all categories of results. Three of the key categories are also presented as diagrams in order to better illustrate the differences between the different setups. The complete results can be found in Appendix C.

	Average of sturdy linkage type	Average of cable tie linkage	Average of unlinked chairs
Number of aisles that have been blocked	0,25	2,5	6,33
Number of disturbed rows of chairs with the aisle still unblocked	0,5	0,5	1,33
Number of rows of chairs still intact	7,25	5	0,33
Number of people needing to move a chair in order to evacuate	0	0,5	5
Number of single chairs moved out of position	0,25	4,5	28
Number of people stumbling or getting caught up on chairs	3	2,5	8
Total time of evacuation	38 s	32 s	36,67 s
Number of people using chairs as support	3,5	2,5	5,33
Number of people crossing rows	2,5	0	4,33

Table 6.1 *- Averaged values from the different experimental setups*

Table 6.1 shows that in some aspects the different kinds of linkage types do provide a difference clear enough to say that the result concerning the aspect does depend on what kind of linkage type is being used. These aspects are primarily:

- Number of aisles that have been blocked
- Number of rows of chairs still intact
- Number of single chairs moved out of position

The differences in the others aspects are small. All these aspects will be further analyzed and discussed in Chapter 7.1.

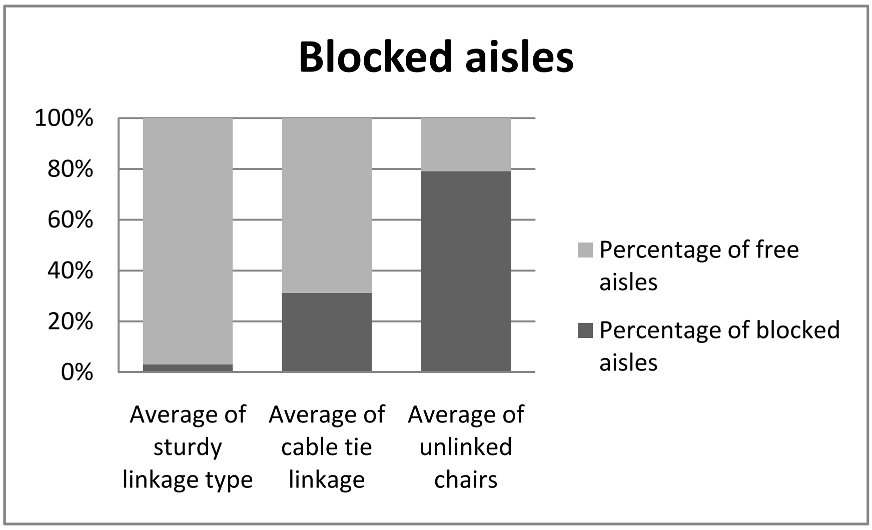

Figure 6.7 *- Average percentage of blocked aisles*

Figure 6.7 shows the very clear difference between the results concerning blocked aisles. The difference is extremely obvious comparing the results from the experiments with the sturdy linkage type, where nearly all aisles remained available, and the results from the experiments with unlinked chairs where the just opposite is true, i.e. nearly all aisles were blocked.

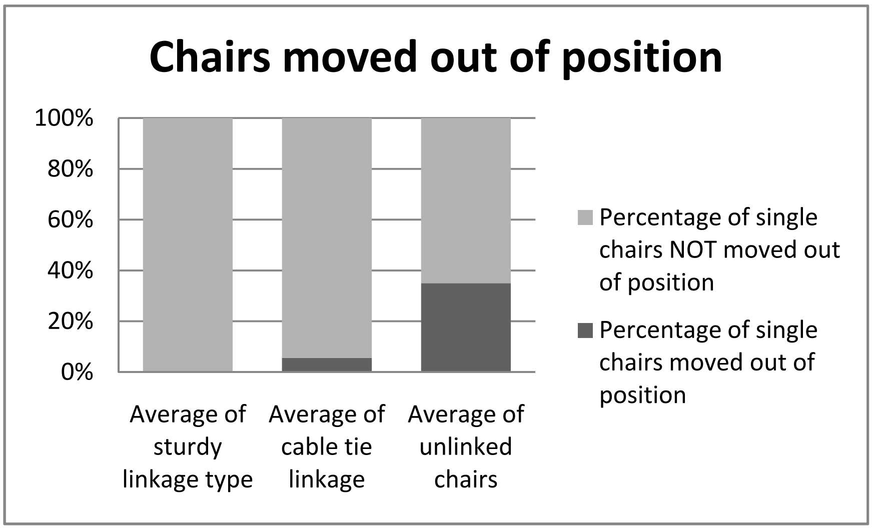

Figure 6.8 *- Average percentage of single chairs moved out of position*

Figure 6.8 shows the also very clear difference between the results concerning the percentage of chairs moved out of position. In average, more than every third chair was moved out of its position during the experiments with unlinked chairs, while only one single chair was moved out of position during the experiments using the sturdy linkage type (due to temporary poor linkage). In the experiments with cable tie linkage nearly every tenth chair was moved out of its position, even though the chairs actually are linked together.

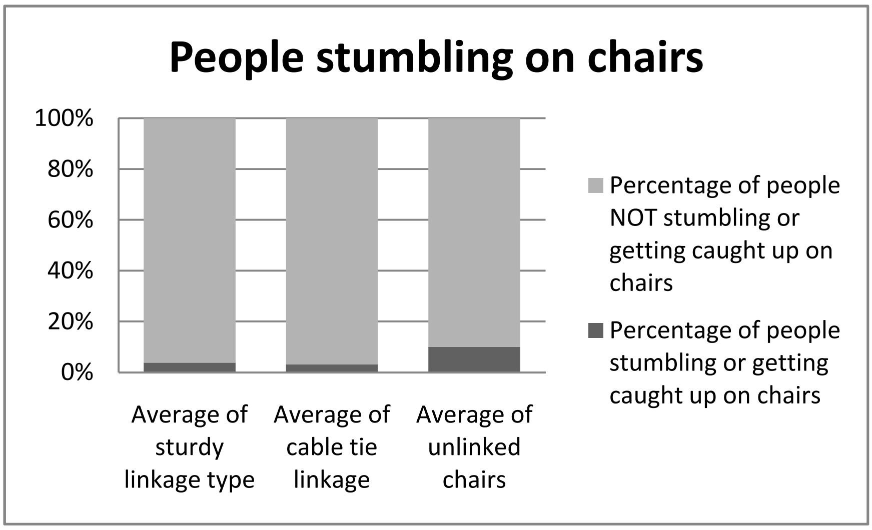

Figure 6.9 *- Average percentage of people stumbling or getting caught up on chairs*

Seen in Figure 6.9, the differences in the amount of people stumbling or getting caught up on chairs between the different experiments types do not vary that much in absolute number, but the relative difference is quite obvious with nearly three times more people stumbling or getting caught up on chairs during the experiments with unlinked chairs than during the experiments where the chairs were linked together. The difference in the result for this aspect between the sturdy linkage type and the cable tie linkage is however negligible.

6.2.2 Flow of persons through the exit

To further quantify the results the flow of persons trough the exit was studied. The number of persons passing through the exit during an interval of five seconds for each linkage method was examined.

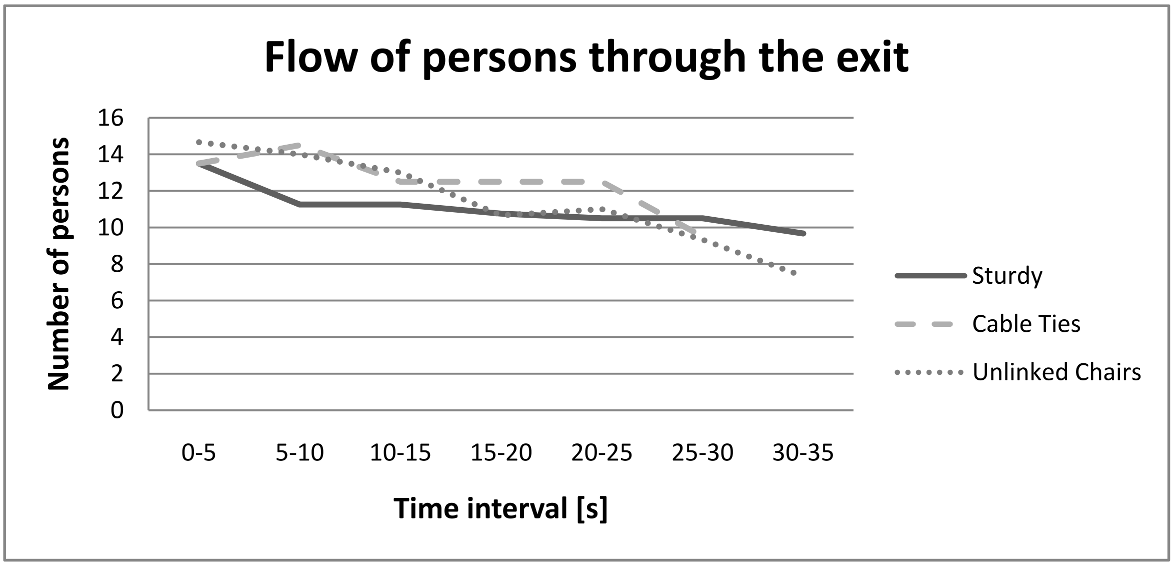

Figure 6.10 *- Number of people passing through the exit during a time interval of five seconds. The average of each linkage method is presented.*

As seen in Figure 6.10 the flow of persons passing through the exit in the experiment using the sturdy linkage method is more even than for the other linkage methods, which show a greater decrease in flow of persons in time. This is reasonable due to the fact that the chairs do not move as much as in the experiments using cable ties and unlinked chairs.

6.3 Observations during the experiments

In the experiments with the sturdy linkage type there was almost no movement of the chairs at all. In these four experiments only one single chair were moved out of the rows of chairs by somehow becoming disconnected from the wooden spar. The only other movement of the chairs observed was that the entire rows were moved slightly in one direction, but it was basically negligible. When pushed, the rows still remained perfectly straight.

In the experiments with cable ties there was considerably more movement of both the rows themselves and the chairs within the rows. Chairs were more easily disconnected from the rows, making them an obstacle in the aisles. The rows were more easily moved than in the experiments with the sturdy linkage, and when moved they went from being straight to a more wavelike pattern with chairs jutting out randomly. Once a chair was displaced and jutted out of the row it was hard to move it back into the row because other chairs filled its space. The displaced chairs were despite their displacement often still attached with at least some of the four cable ties used for each chair, making them an obstacle hard to move out of your way. These chairs were particularly dangerous since they would not move back into the row, neither away from the row because it was still partly attached.

In the experiments with unlinked chairs most of the chairs were moved instantly when the evacuees rose. Then the chairs were moved partly because some evacuees pushed the chairs around in order to evacuate faster, but mainly because of the crowding, especially in the end of the row closest to the aisle where the evacuees turned. The closer the chairs were to the aisle the more they had been moved out of position. Approximately two meters from the aisle into the rows there was no sign of the original setup with all the chairs positioned irregularly. Basically the setup became a chaotic looking mess, see Appendix B.

6.4 Results from questionnaires

The following diagrams show the results from the questionnaires.

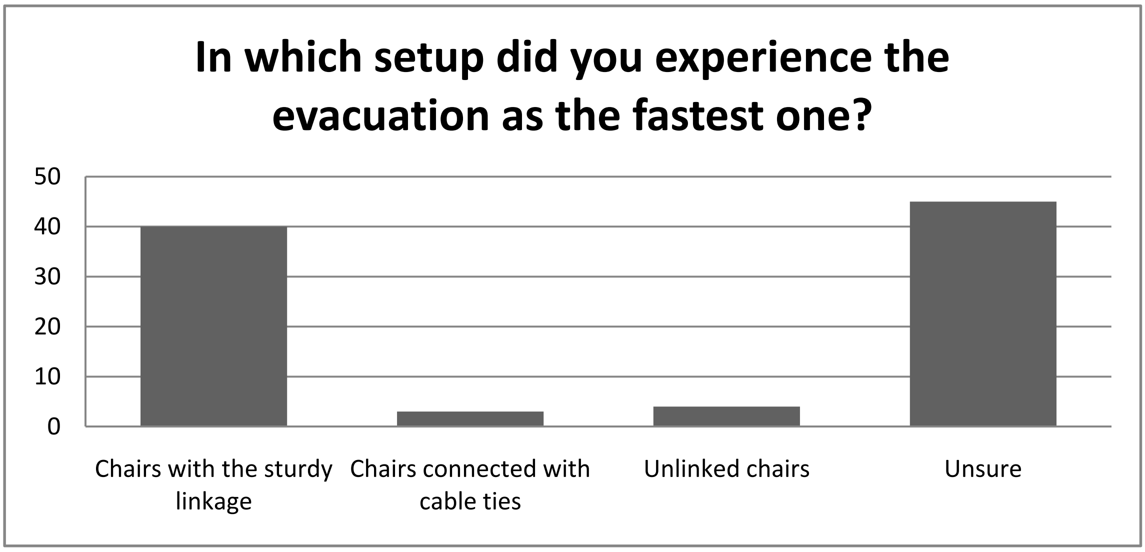

Figure 6.11 *- Answers in absolute numbers to the first question in the questionnaire.*

Even though the total evacuation time was quite similar between all experiments, nearly half of all participants (40 out of 91) experienced the evacuation during the experiments with sturdy linkage type to be the fastest one. A slight majority were unsure, which is the most expected answer with the evacuation times so similar to each other. The average evacuation time of the experiments with chairs connected with cable ties was just a few seconds faster than the other two experimental setups, and there were actually a few participants who actually got this right.

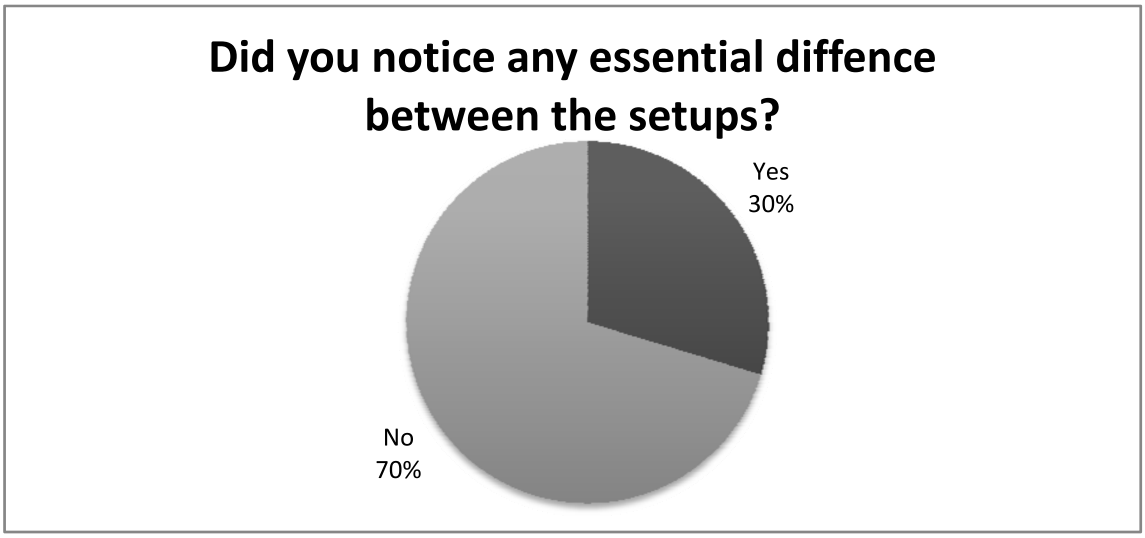

Figure 6.12 *- Answers in percentage to the second question in the questionnaire.*

A clear majority answered that they did not notice any essential difference between the different setups. One major issue with the questioning is that the participants most likely have different opinions and views on what they themselves recall as essential (time of evacuation, chairs moved out of position etc?).

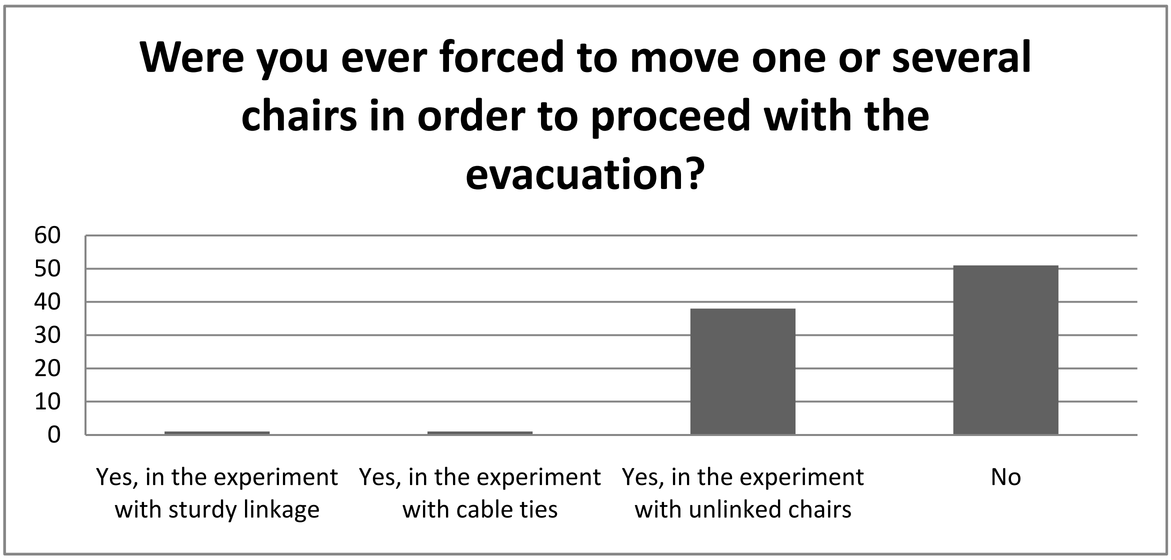

Figure 6.13 *- Answers in absolute numbers to the third question in the questionnaire.*

More than every third participant had to move a chair in order to continue the evacuation during the experiments with unlinked chairs, while half of the participants did not. This is reasonable due to the fact that participants closest to the exit had completed their evacuation earlier than others positioned further away from the exit, and so they did not experience the disorder created later on the in the evacuations with unlinked chairs.

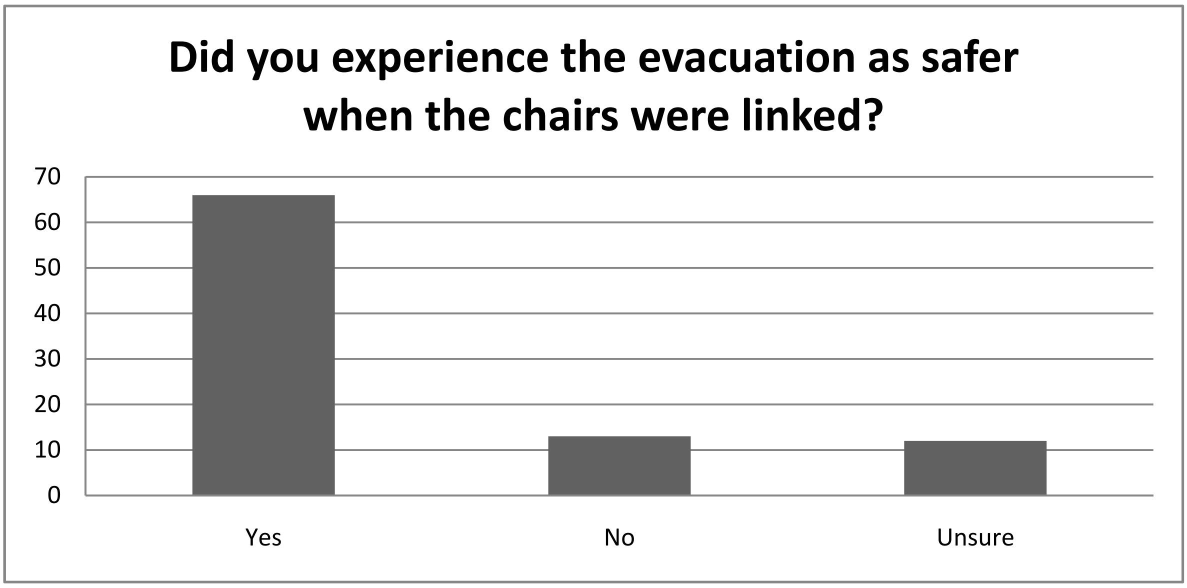

Figure 6.14 *- Answers in absolute numbers to the fourth and final question in the questionnaire.*

Two out of three people experienced the evacuation as safer when linked chairs were used. One problem with the questioning is that the participants are very likely to have different opinions in what criteria they by themselves have for what a safer evacuation is. This problem could be overlooked by the fact that it is a very vast majority who consider the evacuation to be safer with linked chairs.

6.4.1 Comments from the evacuees

Some comments were selected to be presented from all the comments that were given by the participants. The selected comments are viewed as representative for many other comments, and the authors of the report recall them as most relevant. All the comments from the participants can be read in Appendix D. The comments will be further examined and analyzed in Chapter 7.

Comments on question 2: Did you notice any essential difference between the setups? If you answered yes, what was the difference?

"Chairs slipped apart and some people got an advantage of this while some got a disadvantage."

"Fewer loose objects provided an easier evacuation."

"You could get hurt when the chairs were not linked together."

"People took shortcuts and pushed more with loose chairs."

"There was more chaos with loose chairs."

"It was much more unstructured with loose chairs."

"One chair fell over in front of me when the chairs were loose. Scary!"

"When the chairs fell over they made the evacuation more difficult."

"The loose chairs got in the way and people had to push them around."

"The evacuations went more smoothly with sturdy linkages and it was more difficult to trip the chairs down."

"People moved around and tripped down chairs in order to evacuate faster."

Other comments:

"In a real situation I would have hurried more and pushed on the people in front of me."

"More organized evacuation with linked chairs. People did not push the chairs around so much. But more panic related feelings if you are sitting in the place furthest from the center aisle and must stand in line to get out, without being able to take shortcuts between the chairs as you could when they were unlinked."

"The evacuees were too disciplined."

"The pressure from the people in the middle aisle was very uncomfortable and a bit frightening. I can only imagine what it would have been like if panic would have occurred."

"Unfortunately I did not notice any difference at all between the experiments."

The comments from the participants either confirmed or illustrated many risks concerning the effect of loose chairs on evacuation. They also confirmed the advantages of having chairs linked together. The evacuations with loose chairs are commented as disturbed, disordered and chaotic while they evacuations with linked chairs are commented as much more easygoing and safer.

7 Discussion

In this chapter the authors will present their opinions and thoughts concerning the results of the experiments. Factors that might have affected a real evacuation, will also be analyzed. Finally possible biases will be discussed.

7.1 Results

In Table 6.1 there are four categories which are all related to the position of the chairs after the experiments. These are the ones concerning blocked or intact aisles and the position of single chairs. With regard to the number of aisles that became blocked, there is a distinct and definite difference between the experiments with loose chairs and chairs linked together. With the difference being so substantial, it is clear that linked chairs do prevent aisles from getting blocked during an evacuation. The difference between the two kinds of linkage types used shows that there is a clear difference in favor of the sturdy linkage method, with basically no aisles having been blocked. In the case of this particular aspect, the sturdy linkage type will provide a safer evacuation.

As for the number of rows of chairs still intact after the evacuation, there is a substantial difference between the cases with loose chairs and chairs linked together. With the sturdy linkage type nearly all rows were intact, while in the cases with loose chairs nearly all rows were disturbed. In the case where the chairs were linked together with cable ties, nearly half of all rows were disturbed. And so, when considering this aspect, the authors find the sturdy linkage method to be significantly safer than the other two setups.

When considering the number of single chairs moved out of position in the experiments, there is a clear difference in favor of the linked setups. However, the difference between the results for the sturdy linkage type and the cable tie linkage is negligible. And so, it can only be said that linked chairs provide a safer evacuation in this aspect.

The difference between the time of evacuation for the different setups is small and negligible. But the fact that this difference is negligible does not by itself say that there is no difference in the safety of an evacuation between the different setups. There are a number of factors affecting a real scenario that might significantly increase the hazard of an evacuation. This will be further evaluated in Chapter 7.2.

As for the number of people that stumbled or got caught up on chairs, there is only a small difference between the setups with chairs linked together and loose chairs. The authors do not find this difference to be clear enough to draw any conclusions. People stumbling or getting caught up on chairs is closely related to the number of people using chairs as support. This category of result was quantified in order to see if people use chairs as support to guide themselves in the evacuation. The only conclusion that can be made is that a few people do use chairs as support in all the three different setups, with little difference between them. This aspect might be affected by the visibility and will be further evaluated in Chapter 7.2.

In regard to the number of people crossing rows, there are slightly more people who do this in the setup with loose chairs than with the setups with linked chairs. The reason people did this was to get ahead in the queue resulting in delaying the crowd behind them. In the case with loose chairs the people crossed rows by moving the chairs, thereby blocking the aisles for the others. In the case with chairs linked together the people crossed rows by simply stepping over the rows of chairs leaving the aisles intact. However the difference in the results between the setups is too small to draw any conclusions.

The effects of the *moles* during the experiments were negligible in all setups. The moles only managed to move at most one chair each in every experiment, which is insignificant when compared to the movement of the chairs by the other 78 people.

7.2 Factors affecting a real scenario

There are several factors which might have affected the outcome in a real scenario compared to the experiments, the main factor being smoke and limited visibility, but also the possible presence of disabled people.

With decreased visibility, it is likely that people will stumble, move and use chairs as support to a higher degree. This would mean that the sturdiness of the setups would be more important in order to maintain the position of the chairs and thereby making sure that the aisles do not become blocked. Any flaw in the setup would likely be magnified, making the difference between the setups more distinct. The effect of smoke will likely add to the level of crowding because the evacuees will experience fear and perceive the situation as dangerous. The presence of smoke will likely affect the evacuation in a way similar to decreased visibility, therefore further emphasizing the need for a sturdy setup of the chairs.

The evacuees of the experiments were all healthy and young people with no disabilities. The presence of disabled or elderly people would require a sturdier setup of chairs since their ability to move chairs blocking their aisle is limited. As a result, the need for a sturdy linkage method is strengthened to make sure that the rows stay intact during the evacuation.

7.3 Effect of the type of chairs used

The chairs used in the experiments were not ideal for linking together because of the curved armrests. The armrests were the only part of the chairs that were in contact from chair to chair, making it hard to find an appropriate way of linking them together. This goes for both the sturdy linkage but more so for the cable tie linkage. Had another type of chair been used, a type without armrest, the stability of the two linked setups would likely have been improved. The cable tie linkage would likely have improved more in relative to the sturdy linkage.

7.4 Questionnaires

The questionnaires show that the evacuees found the setups with chairs linked together to be safer, especially the setup with the sturdy linkage type. However, a majority did not consider the difference between the setups as significant. One problem with these two questions is that the answers do not say in what way the sturdy linkage type was safer and the evacuees might have different views on what a significant difference is. The comments from the evacuees show that they experienced the different setups as similar but that they are still aware of the possible hazards and believed a real situation would have been more dangerous with loose chairs.

7.5 Biases

There are several biases affecting the results making them less accurate to a real case. One main bias in these kinds of experiments is the fact that people know that it actually is an experiment. This will lead to less urgency in the evacuation and possibly making the people act in a way they would not have done in a real case. Since the evacuees are familiar with the fact that it actually is an experiment, this bias is difficult to remove. Also, since the setups were quite similar to each other, the evacuees might repeat certain behavior from a previous experiment leading to more similar evacuations in the different setups than it otherwise would have been.

One obvious bias is the fact that the participants evacuated immediately after a signal was given. In a real scenario there will always be a delay because of the time of recognition and response, resulting in an evacuation where the evacuees will not start moving towards the exit at the exact same time. Because the part of the recognition and response had been removed from the experiments the fact that the students were familiar with each other is negligible.

One problem with many similar experiments made immediately after one another is that the participants might discover that crossing rows will result in a faster evacuation for the themselves. The authors did not find any other signs of learning effects. The crowd did not behave in the same way in every experiment but there was no sign of any kind of behavior gradually becoming more common or uncommon. For example, in one experiment it was a high level of crowding, while the following experiment with the same linkage method was calmer. Then in the next experiment there was a high level of crowding again. The changes in behavior were random.

8 Conclusion

The experiments show that the evacuation using chairs linked together is significantly safer than loose chairs. Therefore there should be a requirement for setups of loose chairs to be linked together if they are to be used in assembly halls. There is also a clear difference between the results from the setups using chairs with sturdy linkage, and chairs linked with cable ties. The experiments show that a sturdy linkage type does provide a significantly safer evacuation, especially when considering the effect of smoke and the presence of disabled people. This aspect suggests that just linking the chairs together is not enough; a sturdy linkage method should be required by the authorities.

9 Further studies

The experiments showed a definite difference in favor of a sturdy linkage method over a less sturdy one. However, it remains unclear what level of sturdiness is needed for the rows of chairs to perform well enough during an evacuation. A European standard for testing the performance of the links holding the chairs together exists, but these tests may hold little or no relevance to evacuation since their development have not been based on a scientific approach on evacuation. These tests are also dependent on which models of chairs are used; leaving the type of chairs used a variable. This means that one type of linkage can be approved of by the standards institute and still not perform well enough when used with different chairs than tested with at the institute. Further studies can be suggested to evaluate the level of sturdiness needed in order for the rows of chairs to perform well enough during evacuation. It would also be appropriate to assess the impact of smoke and/or elderly people on these types of evacuations. Other suitable aspects to study further are the impact of the number of chairs in each row, the distance between the rows or a higher total amount of people. Different types of chairs or linkage methods also needs to be studied further.

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Appendix A – Questionnaire from the experiments

1. In which setup did you experience the evacuation as the fastest one?

□ Unlinked chairs

□ Chairs connected with cable ties

□ Sturdy linkage

□ Unsure

2. Did you notice any essential difference between the setups?

□ Yes

□ No

If you answered yes, what was the difference?

3. Were you ever forced to move one or several chairs in order to proceed with the evacuation?

□ Yes, in the experiment with: □ unlinked chairs □ cable ties □ sturdy linkage

□ No

4. Did you experience the evacuation as safer when the chairs were linked?

□ Yes

□ No

□ Unsure

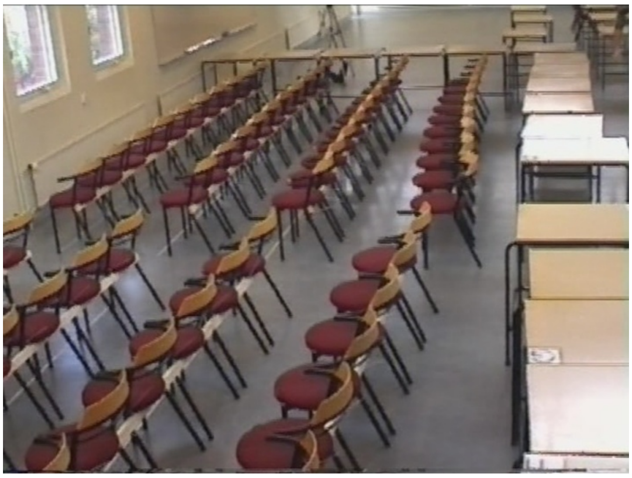
Other comments:

Thank you for participating!

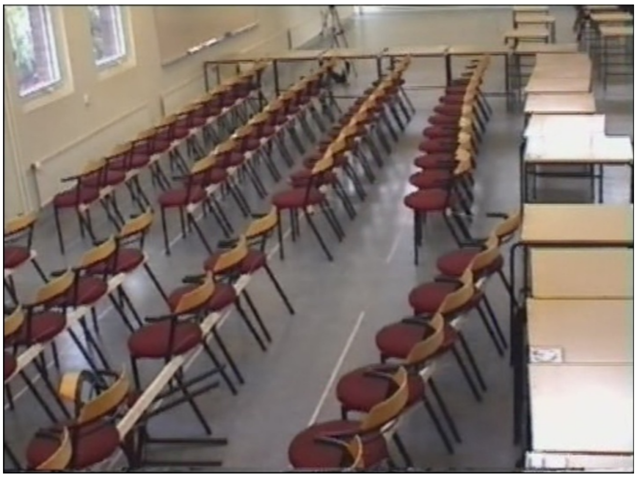
Appendix B – Pictures from the experiments

In this appendix screenshots from the video recordings from each experiment will be presented. The screenshots below show how the setup looked after each evacuation had taken place. The picture on the left side shows camera position A, and the picture on the right side shows camera position B.

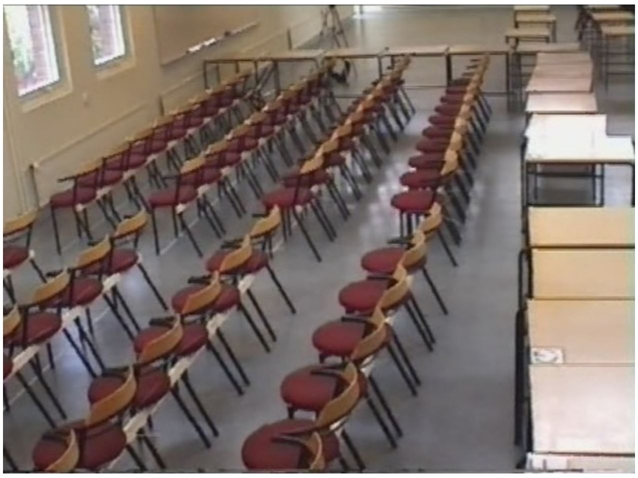
Sturdy linkage experiment 1



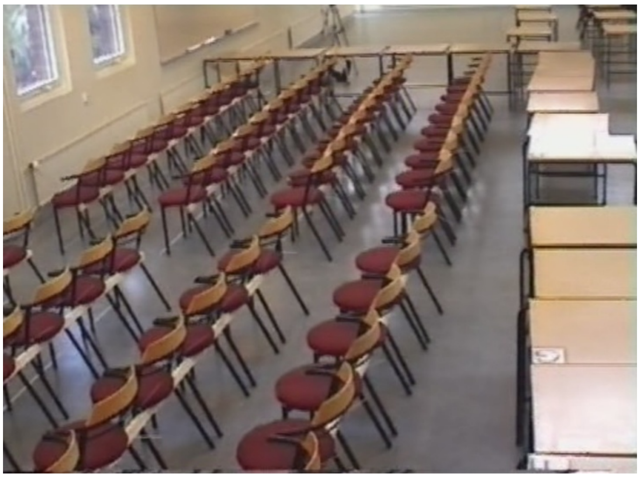
Sturdy linkage experiment 2

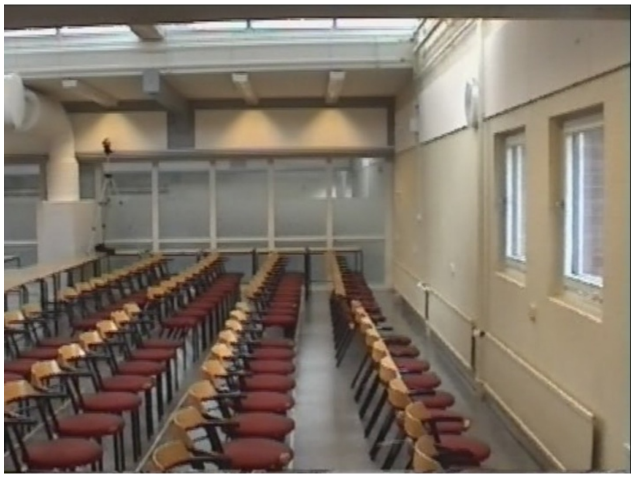


Sturdy linkage experiment 3



Sturdy linkage experiment 4





Cable ties experiment 1

Cable ties experiment 2

Unlinked chairs experiment 1

Unlinked chairs experiment 2

Unlinked chairs experiment 3

Appendix C – Complete results

	Sturdy linkage - First experiment	Sturdy linkage - Second experiment	Sturdy linkage - Third experiment	Sturdy linkage - Fourth experiment	Average
Number of aisles that have been blocked	0	1	0	0	0,25
Number of disturbed rows of chairs with the aisle still unblocked	1	1	0	0	0,5
Number of rows of chairs still intact	7	6	8	8	7,25
Number of people needing to move a chair in order to evacuate	0	0	0	0	0
Number of single chairs moved out of position	0	1	0	0	0,25
Number of people stumbling or getting caught up on chairs	4	2	5	1	3
Total time of evacuation	36	37	39	38	37,5
Number of people using chairs as support	7	2	3	2	3,5
Number of people crossing rows	5	3	1	1	2,5

Table 10.1 *- Results from experiments with sturdy linkage*

	Cable ties - First experiment	Cable ties - Second experiment	Average
Number of aisles that have been blocked	3	2	2,5
Number of disturbed rows of chairs with the aisle still unblocked	1	0	0,5
Number of rows of chairs still intact	4	6	5
Number of people needing to move a chair in order to evacuate	1	0	0,5
Number of single chairs moved out of position	6	3	4,5
Number of people stumbling or getting caught up on chairs	3	2	2,5
Total time of evacuation	30	34	32
Number of people using chairs as support	4	1	2,5
Number of people crossing rows	0	0	0

***Table 10.2** - Results from experiments with cable ties*

	Unlinked chairs - First experiment	Unlinked chairs - Second experiment	Unlinked chairs - Third experiment	Average
Number of aisles that have been blocked	5	7	7	6,33
Number of disturbed rows of chairs with the aisle still unblocked	3	0	1	1,33
Number of rows of chairs still intact	0	1	0	0,33
Number of people needing to move a chair in order to evacuate	3	4	8	5,00
Number of single chairs moved out of position	19	38	27	28,00
Number of people stumbling or getting caught up on chairs	7	8	9	8,00
Total time of evacuation	37	37	36	36,67
Number of people using chairs as support	7	3	6	5,33
Number of people crossing rows	1	4	8	4,33

Table 10.3 - *Results from experiments with unlinked chairs*

	Average of sturdy linkage type	Average of cable tie linkage	Average of unlinked chairs
Number of aisles that have been blocked	0,25	2,5	6,33
Number of disturbed rows of chairs with the aisle still unblocked	0,5	0,5	1,33
Number of rows of chairs still intact	7,25	5	0,33
Number of people needing to move a chair in order to evacuate	0	0,5	5
Number of single chairs moved out of position	0,25	4,5	28
Number of people stumbling or getting caught up on chairs	3	2,5	8
Total time of evacuation	37,5	32	36,67
Number of people using chairs as support	3,5	2,5	5,33
Number of people crossing rows	2,5	0	4,33

Table 10.4 *- Averaged results from each linkage type*

Appendix D – Comments from questionnaires

Comments on question 2: Did you notice any essential difference between the setups? If you answered yes, what was the difference?

"When a chair fell over it felt as if the evacuation went slower."

"Ability to move chairs and create new paths."

"I hurried up more in the last few experiments."

"The chairs did not fall over when they were linked."

"The chairs fell over when they were not linked."

"Chairs slipped apart and some people got an advantage of this while some got a disadvantage."

"With unlinked chairs they were movable and became objects to trip over. The biggest limitation was the door so the total time of evacuation probably was the same. Some individuals could get out faster/be slowed down depending on how the chairs were moved."

"Fewer loose objects provided an easier evacuation."

"You could get hurt when the chairs were not linked together."

"In the last experiment chairs that had fallen over blocked the aisle."

"People took shortcuts and pushed more with loose chairs."

"Fewer chairs fell over when they were linked."

"There was more chaos with loose chairs."

"When the chairs were loose, there was more congestion."

"The chairs fell over when they were loose."

"It was much more unstructured with loose chairs."

"One chair fell over in front of me when the chairs were loose. Scary!"

"The more experiments, the lesser cooperation between the evacuees."

"When the chairs fell over they made the evacuation more difficult."

"The loose chairs got in the way and people had to push them around."

"The evacuations went more smoothly with sturdy linkages and it was more difficult to trip the chairs down."

"The evacuations went much more smoothly when the chairs were linked together."

"People moved around and tripped down chairs in order to evacuate faster."

"The chairs were moved around or fell down when people were pushed towards them."

"The chairs felt over when they were not linked together."

Other comments:

"In a real situation I would have hurried more and pushed on the people in front of me."

"Perhaps slightly more crowded when the chairs were linked with spars."

"Some (including me) stepped on the chairs to cross a row to get ahead in the line. It felt as if the chance of falling was greater with unlinked chairs."

"More organized evacuation with linked chairs. People did not push the chairs around so much. But more panic related feelings if you are sitting in the place furthest from the center aisle and must stand in line to get out, without being able to take shortcuts between the chairs as you could when they were unlinked."

"The evacuees were too disciplined."

"The chairs were not moved around so very much but got stuck on the arms of the chairs whether they were linked or not."

"The pressure from the people in the middle aisle was very uncomfortable and a bit frightening. I can only imagine what it would have been like if panic would have occurred."

"Unfortunately I did not notice any difference at all between the experiments."

"At some occasions the chairs fell down."

"The chairs might fall down and block the aisles."

"I thought the difference between the different setups was going to be bigger."

"Congestion is bad."