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Justification Report

Crowd safety standards and crowd behaviour during evacuations

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Contents

Preface

This justification report has been created for the graduation assignment at the Breda University of Applied Sciences. Research has been done to find solutions for my client, Logistics Community Brabant. The conducted desk and field research, the explanations, and the justification for decisions taken, can be found in this document.

I want to thank Logistics Community Brabant for providing me the chance to work on this project, especially my supervisors Quinten Kentie and Sanne Kuipers. I value your respect and the freedom you have given me to work on a subject I am passionate about while utilizing my creativity and professional competence. I want to express my gratitude to Dorothé Gerritsen, my university's supervisor, for his constant support and assistance with the project during this semester. I am also appreciative of my other graduating students and classmates for always being willing to provide a hand and constructive feedback. I also want to thank my interviewees Armin Seyfried and Syan Schaap. Without your knowledge and input I would have not been able to fully complete this assignment.

I want to express my gratitude to everyone for their time, assistance, and support over the past several months.

Sincerely,
Katrin Vollenkemper

Executive summary

This assignment focusses on an assignment by the Logistics Community Brabant, a business based on the campus of the Breda University of Applied Sciences, which provides innovative products in six different areas to interested customers. One area focusses on event logistics and deals with smart and efficient logistics at events. Safety within crowded places during events has become more important due to the increasing number of visitors at events. To ensure the most safety, guidelines have been created in different European countries, which give key figures to follow when executing an event. Research suggests that there are differences between the key figures in different countries. The core challenge, therefore, is that LCB wants to understand which key figures are the most reliable and should be used when organising an event. Accordingly, the objective of this assignment is to *"create insights into safety standards and crowd behaviour during evacuations in the Netherlands."* This assignment draws on desk research, a creative session, an experiment, and expert interviews.

Desk research has revealed the differences in safety key figures between the guidelines of the UK, the Netherlands, Germany, and Sweden, like the throughput of a door and stairs. A creative session with safety experts from various fields has uncovered that different key figures are being used among the experts. The input has been used to execute an experiment, analysing the throughput of a one-metre-wide door and one-metre-wide stairs. The experiment revealed key figures of 110 people per minute per metre through a bottleneck and 60 people per minute per metre using the stairs. Furthermore, the desired behaviour of the crowd during an evacuation has been analysed using desk research and expert interviews. It revealed that the behaviour can only be predicted to a certain extent, since every crowd behaves differently in different situation.

Based on the experiment and expert interviews it is recommended to use the guidelines that show the lower key figure, due to the missing disrupting factors during the experiment. The guideline from the UK suggests a throughput of 82 people per minute per metre through a bottleneck. The guideline from the Netherlands suggests 45 people per minute per metre using the stairs. By following these key figures, the most safety is ensured during an event.

Further research into this topic needs to be done, due to the numerous differences between the European countries. This project was aimed as a first trail, which helped in understanding the process of executing an experiment. Soon, more experiments on this topic will be executed by LCB.

1. Company background information

1.1 Introduction

This chapter contains all needed information on the Logistics Community Brabant (LCB), including the vision, mission, strategy, as well as the products and services. LCB was founded in 2017 to encourage the quick exchange of logistical information between businesses and academic institutions. It is a collaboration between several universities in the region of Brabant (Colphen & Partners, 2017). LCB focuses on six different areas: Date Driven Logistics, Liveable City, Healthcare logistics, Smart Industry, Multimodal and Event Logistics. Each topics has its own team and projects and products (LCB, 2022).

1.2 Vision, mission, and strategy

LCB's mission is to cleverly bring together the information needs of companies and the knowledge supply of knowledge institutions in the field of logistics in the province of North Brabant, increasing the effectiveness of renewing both business models and knowledge (Colphen & Partners, 2017).

The vision of Logistics Community Brabant is to coordinate knowledge-based growth. Because LCB serves as an intermediary station that connects the various groupings, its role is crucial. The role is depicted schematically in Figure 1. The terms "digital transformation," "innovation," "omni channel," and "sustainability" are bandied about in it within the relevant circles. These subjects are seen as crucial elements (Colphen & Partners, 2017).

The Logistics Community Brabant has several building blocks that make up the strategy. Together, these building blocks form the sentence: "**Community** with **central companies** and **smart products** across **six themes** that are also **proactively** offered with the main theme of **innovation** via **one-stop shopping** for the benefit of better **knowledge flows** based on high-quality **communication**, marketing and PR **across borders** but based in **Breda**" (Colphen & Partners, 2017).

1.3 Products and services

LCB develops innovative products that are based on the interest of the client. The main product is always based on research into one of the six areas. Clients and customers are able to participate in workshops, trainings, courses, or tailor-made programs. Members of the community benefit attractive discounts (LCB, 2023).

2. Challenge

LCB is involved in the logistic processes and crowd management of events and therefore, has much knowledge on this topic. Previous research has shown that the safety within crowded public places can be improved by managing the crowd's behaviour and organising the processes safely. To know how a crowd will behave in certain situations is crucial for crowd management. However, it is very difficult and therefore, LCB has opened a Crowd Science Research Lab (CSR lab) on the BUas campus. They want to collaborate with different partners and carry out experimental research. The partners are from universities and from the industry (personal communication, 2023).

LCB plans to start in phase one in a static environment. Afterwards they want to move to the industry and conduct research in a dynamic environment, meaning fesitvals and other events. The final phase will be in the public environment. That would be big events in a municipality, but also markets and busy squares. The research is focused on crowd behaviour, visitor flows and collecting data for the field of crowd safety (personal communication, 2023).

LCB is planning to create a knowledge bank, which will gather the collected data from the experiments and research in form of knowledge clips, infographics, reports and essays. This knowledge bank will be available to experts from the industry, but also other people, who are interested into the safety measures at events (personal communication, 2023).

2.1 Reason of research

The client – LCB – wants to improve the safety within crowded places during events. Each event organiser needs to follow the safety regulation stated in safety guidelines and regulations by the municipalities. However, there are numerous guidelines within the Netherlands and other European countries. The key figures in the guidelines differ between the countries and it leaves room for interpretation for the event organisers. The aim of the project was to either confirm or correct the safety related numbers stated in the guidelines to create an overview for the stakeholders to use at future event.

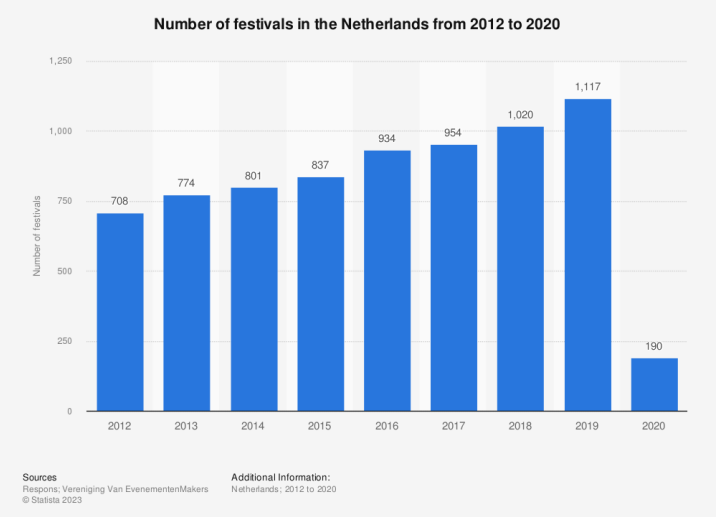

Figure 1 - Number of festivals in the Netherlands from 2010 to 2020 (Response, 2020)

Over the past few years, the number of festivals and other events has increased, and the size of events are also increasing, attracting more visitors. According to Statista, the number of festivals in the Netherlands has been growing continuously until 2019. In 2012, 708 festivals took place in the Netherlands and in 2019 it grew to 1.117 festivals (Response, 2020). Due to the pandemic, this trend has been halted. In 2022, after all safety measures have been lifted by the government, the numbers started rising again and are close to the number pre-pandemic, according to Vibrate (Vibrate, 2022). Therefore, safety measures are more important than ever. Venues need to be able to manage the number of visitors and ensure safety for everyone visiting. New event organisers might not be familiar with organising an event and therefore lack knowledge in safety related issues. This can lead to incidents that could have been prevented. It is important to share the knowledge and ensure the most safety at the events.

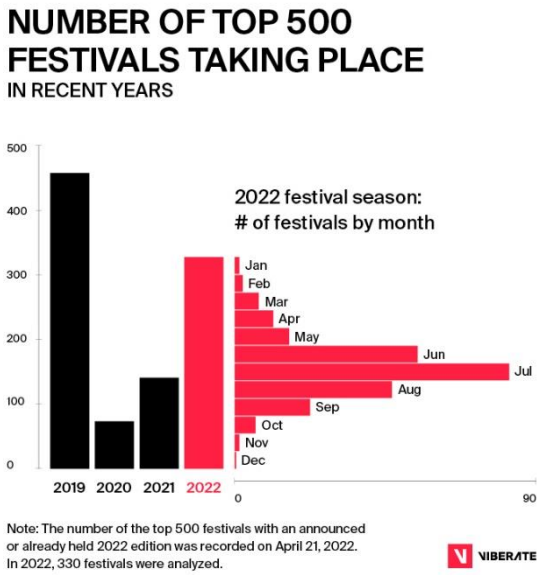

Figure 2 - Number of festivals worldwide from 2019 to 2022 (Vibrate, 2022)

2.2 Research objective

The research objective has been defined as follows: “Creating insights into safety standards and crowd behaviour during evacuations in the Netherlands.” The aim is to create more data and awareness on this topic. Safety standards are the baseline of risk assessments, and they need to be accurate and reliable to prevent incidents. The crowd behaviour during an evacuation can have an impact on the evacuation time and therefore needs to be considered.

2.3 Research question

The research question has been defined as follows: “What are the desired safety standards and crowd behaviour in the Netherlands during evacuations?”

The sub-questions have been defined as follows:

1. How many people can pass through a doorway with a width of 1.00 m per minute?
2. How many people can pass a staircase upwards with a width of 1.00m per minute?
3. How many people can pass a staircase downwards with a width of 1.00m per minute?
4. What influences the crowd behaviour during an evacuation?

2.4 End product

The end product that has been created for LCB is a knowledge clip focusing on the key figures during an evacuation of an event, focussing on the throughput of a door and staircase. LCB wanted to improve the safety at events, by providing valuable information and key figures to the experts of the industry. For this goal, they developed a knowledge bank where knowledge clips and further information can be published in the future. The goal of LCB was to create clips that would be published in the knowledge bank and are being used by the experts during trainings or lectures. They should show the importance of this topic, the research that has been done and the experiments that have been conducted by the research team, including the results.

In connection to the knowledge clip, an short essay has been written to further explain the challenge and the theories used during the experiments. The essay is aimed at the experts, who are interested to learn more about the research and the experiments than from the knowledge clip. Within this essay, a more detailed explanation is given, using jargon and theories to explain the challenge more detailed.

2.5 Competency domain

Professional event managers use the competence domains to aid in problem-solving. running businesses, leisure productions, design and marketing, and stakeholder management are some of these areas.

For this project, the competency domain that fits best is leisure productions, as it focuses on creating a memorable experience for the target group during an event. During this project for LCB, the experiments have been seen as a small event and were organised with an imaginative approach. This also includes the concrete planning, the logistical aspects, the measurement, and communication plan for the experiments.

The competency domain of stakeholder management has only been used at the beginning of this project. The focus was on creating a collaboration between different stakeholders to ensure safety at events in the future. For this, a kick-off meeting with a creative session have been set up, so the stakeholders are able to connect and work together in the future within the CSR-Lab created by LCB. However, during the project, the focus shifted to the competency domain of leisure productions, since the creation of the experiment, did not involve many stakeholders and the collaboration will be managed by LCB in the future.

3. Methodology

To gather the most essential information for the client, a methodology has been created, using desk and field research. This way, the optimal end product for the client has be produced this is in line with the client's vision and the competency domains.

3.1 Desk research

Desk research was used in the beginning of the project to gather an overview of the already existing data. To gather the most valuable information the diverge and converge method has been used (Thoring & Mueller, 2011). After defining the problem, research has been executed in different directions. This approach included previous research, articles, reports, books, experiments, and the safety guidelines from different countries. Thinking outside of the box has helped gather the most valuable data needed for this project. Once a lot of data has been collected, the converge phase was important to analyse the information. It needed to be decided on specific options and focus areas. Using this technique, the information has been filtered for only the most valuable information to remain. This type of research has helped to create an overview of the key figures within the event industry in different countries, existing experiments, and theories on crowd behaviour during evacuations.

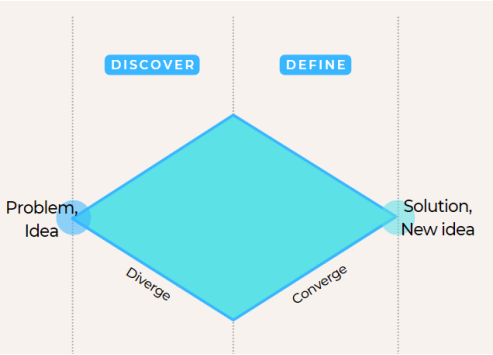

Figure 3 - Diverge and converge method

3.2 Field research

The field research was used to gather more information that was missing during the desk research phase. This project was focusing on gathering qualitative data over quantitative data, therefore, several options to gather information has been scheduled. The first option to gather valuable qualitative date was a creative meeting with experts in the field of safety. During this meeting, the experts were choses from various backgrounds, like the fire department, the Event Safety Institute (ESI) and the Dutch Defence Academy. The aim of the meeting was to gather insights into the expert's experience, knowledge and opinions on safety key figures and safety guidelines of different countries and in the Netherlands. To gather the most useful information and create an open and creative atmosphere during the session, several creative methods have been used. To break the ice in the beginning, a questionnaire with a guessing game has been used to get people warmed up to the topic (Hanifan, 2022). This method was also used to gather insights from different angles, like the usage of different guidelines. Another method was to ask the participants to draw what was written in the Dutch guideline. A paragraph was particularly difficult to understand, therefore, it has been written on a piece of paper and the participants were asked to draw how they interpret the paragraph. The aim was to create a discussion and make the experts aware that written texts in guidelines can be confusing and lead to misinterpretation. The input gathered during the guessing game has been used for further desk research and to improve the planning of the experiment.

Another option to gather information and insights were further interviews with the experts of the creative session, as well as other experts with different backgrounds. An expert from the research institute Jülich in Germany has been interviewed on his experience with executing experiments. During this interview, questions about the set-up of an experiment and the influence of the crowd's behaviour on the experiment have been discussed. The influence of the Covid-19 pandemic on the experiment's results has also been discussed. The interviewee was willing to share his knowledge that he teaches at the university in several lectures. This input has been used for further desk research. Another expert from the Event Safety Institute has been interviewed to help analyse the results of the experiments that have been executed on campus. During the interview, questions about the guidelines and the reliability of the experiment's results have been answered, especially questions about by sub-research questions. Another topic was the crowd behaviour during an evacuation and the psychological impact it has on an individual. Further information has been shared and was used for desk research. This qualitative data has been used during the analysis of this project.

The most important part of the research was to facilitate experiments to gather the missing information from the desk research. The focus was put on the throughput of a door and the throughput

of stairs in normal and high urgency. The experiments were used to gain more qualitative and quantitative data needed for the research, based on the different models and theories analysed in the desk research. In order to ensure the research is reliable and valid, the experiments were executed twice, and numerous measurements were taken during the experiments by the research team. The footage of the cameras was later used for further analysis. Screenshots of the camera footage can be seen below.

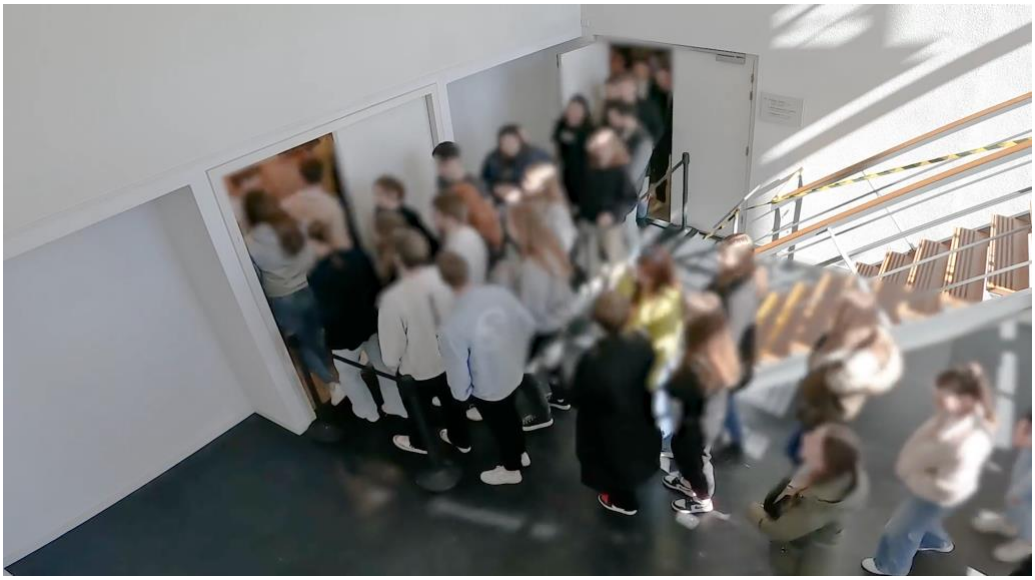

Figure 4 - Experiment on the throughput of a door

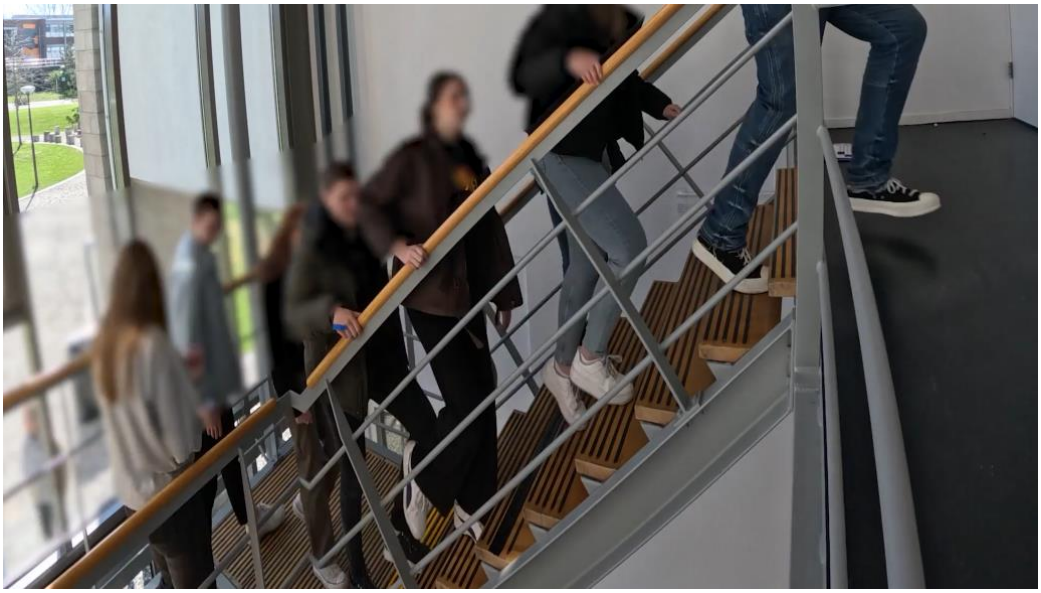

Figure 5 - Experiment on the throughput of stairs

4. Theoretical framework

The models used for this research were the DIM-ICE model and the RAMP-analysis by Keith Still, as well as the analysis model escape safety. These models were chosen because they are the basis of crowd management and safety during an event. They ensure all important aspects are considered. Furthermore, the Guest Experience Model, including the pre-, direct- and post-exposure has been used to create an imaginative experience for the students during the two experiments. Since the experiments are a small event themselves, it is important to engage the students, so the results are reliable. To better analyse the crowd behaviour, the Leisure Behaviour Model of Knulst has been used.

4.1 DIM-ICE model

The DIM-ICE model is one method of mapping the current situation at an event. This model provides insights on the constraints of the design, meaning the capacity and throughput, the information components, like social media and signage, and the management systems, meaning the processes and procedures. Having a thorough understanding of these three elements is crucial for influencing a group of people when they get together. These three aspects are being discussed during the three phases of an event: the ingress, the circulation, and the egress (Still, gkstill.com, 2019).

This model is being used to ensure the reliability of the experiments. It focusses on the ingress and egress phases of an event, but also the impact of the design, information, and management of the crowd. Therefore, it has been used during the planning phase and to create an operational plan that is applicable to any experiment.

Normal	Ingress	Circulation	Egress
Design			
Information			
Management			

Figure 6 - DIM-ICE Model (Still, gkstill.com, 2019)

4.2 RAMP analysis

The RAMP is being used to analyse the dynamics of the crowd. It is based on the Route, Area, Movement, and Persons during an event. These four angles make it easier to understand the audience. The Route helps to prevent crossflows and makes it simpler to understand how the crowd travels. The area demonstrates where the crowd could congregate. The crowd's movement during the event is depicted in the Movement. Examining a certain set of People's profiles is crucial as well (Still, 2018).

This model is being used in preparations for the experiment, since it focusses on the participants, the movement, and the route they are taking. This way, it ensures that all aspects of the experiment are analysed and ensure the most reliable results.

4.3 Guest Experience Model

Another theory is about creating an experience for the participants of the experiments. The 'Guest Experience Model' by Wijngaarden is being used to create an experience for the visitors. The company's vision, purpose, values, and experience idea serve as the cornerstone of this approach. This model's three key pillars are "people," "setting," and "process," which are the places of contact with the guests. These are the service points with whom the customer is in direct contact with. These touchpoints together create the guest experience (Wijngaarden, 2017).

This model is being used to ensure that the experiment is an experience for the participants. The experiment is an event on itself and therefore, needs to be managed that way. Considering and improving the different touchpoints the peoples have with the event ensures a better experience for the participants.

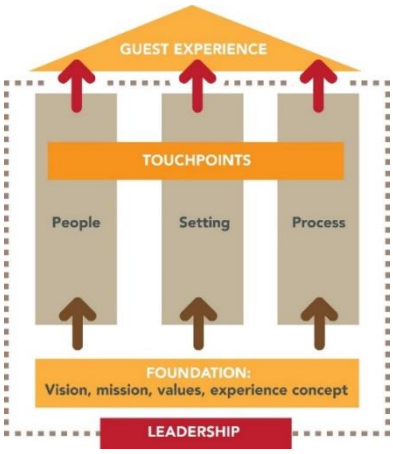

Figure 7 - Guest Experience Model (Wijngaarden, 2017)

4.4 Pre-, direct-, and post-exposure

The Guest Experience Model can be seen in connection with the pre-, direct- and post-exposure model of Moossens. Especially the process pillar can be divided into the three phases. During the pre-exposure phase, the visitors have their expectations towards the event and are already in connection with the website, social media, or other platforms. The visitors engage in a variety of direct exposure activities while they are at the event. They get in touch with the experience and the event. After the guests have left the event, services like showing gratitude, conducting public polls, or advertising are

considered post-exposure activities. Based on the satisfaction of the visitors the intentions for the future will be decided on after the event. If the attitude is positive, the visitor is more likely to return to the event and if the attitude towards the event is negative, the visitor is less likely to return (Moossens, n.d.).

This model is being used to ensure that all phases of the event are being regarded and to ensure a positive influence on the participants.

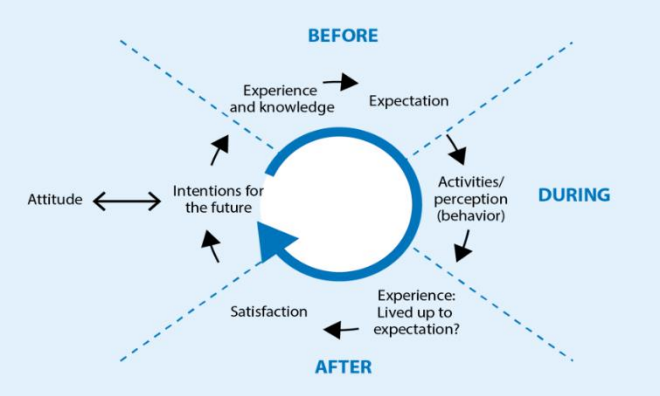

Figure 8 - Pre-, direct-, and post-exposure model (Moossens, n.d.)

4.5 Analysis model escape safety

The analysis model of escape safety is being used to analyse all aspects of the human behaviour in case of an emergency evacuation due to a fire. Important aspects are the characteristics of the people inside the fire, the building characteristic, as well as the fire characteristics. Additional analysis can be done on each factor that have a negative impact on fire self-rescue. Recommendations for enhancing the building's escape safety can be made after a more detailed analysis. It can be used for a new building that is being constructed in the near future, for an existing building, and for a building in which there has been a fire. (Kobes & Oberijé, 2010).

This model is being used to analyse the various influences on a person during an evacuation. It gives input on the behaviour in case of a fire, and it is being compared to other models, to gather an overview of the expected behaviour during an evacuation.

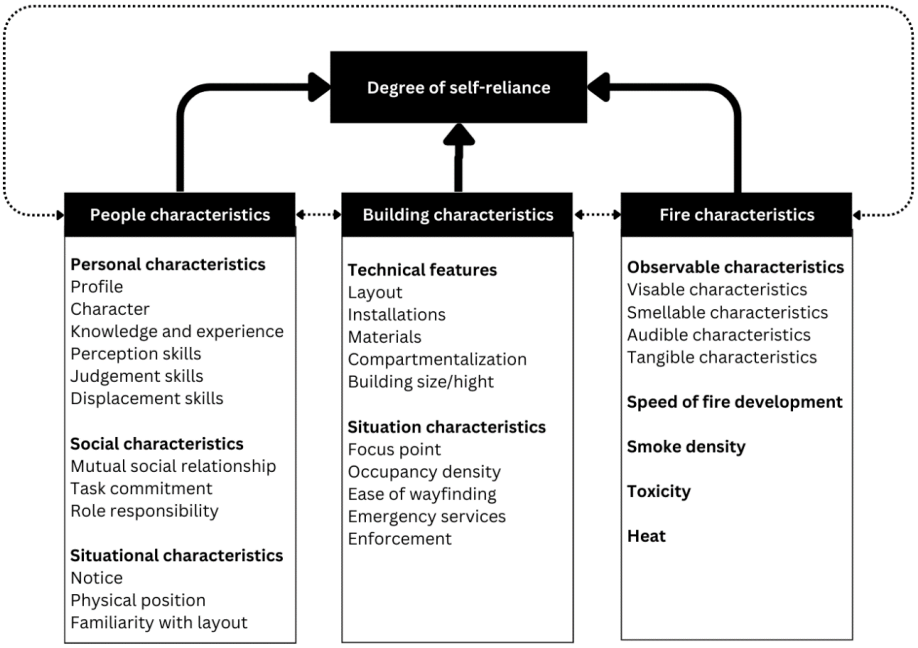

Figure 9 - Analysis model escape safety (Kobes & Oberijé, 2010)

4.6 Leisure behaviour model

The leisure behaviour model of Knulst is being used to analyse the influences on somebody's leisure behaviour. People are being influences by the society they live in through traditions, norms, and values. In every society there are sub-cultures with their own traditions, norms, and values that influence the person's choices. The individual itself can also influence the behaviour through thoughts, attitudes, motivations, and experiences.

Environmental factors are beyond human influence and include geographical and physiological features, like bad weather and the locations. Another factor are the time-spatial constraints, meaning the relationship between the required time and distance needed to be travelled.

Personal preferences are influenced by both the individual and the social setting, or (sub)culture, in which they are expressed. The resources and restrictions are influenced by environmental factors and the four different kinds of capitals: the economic capital, meaning everything someone owns; cultural capital, meaning the individual's knowledge; social capital, meaning social relations and physical capital, meaning the characteristics that shape the individual. The last aspect is the supply, which is depended on the demand and is being influenced by the society, not the individual or sub-cultures.

The government influences these aspects through stimulations, rules, and regulations. The interrupted arrows between personal preferences, resources and restrictions and supply together form our leisure behaviour (Mulder, 2014).

This model is being used to further analyse the behaviour during an evacuation. This model focusses on the individual and how society might influence a person. This can also have an influence on the behaviour during emergencies, so this model is being used to compare with other theories on this topic.

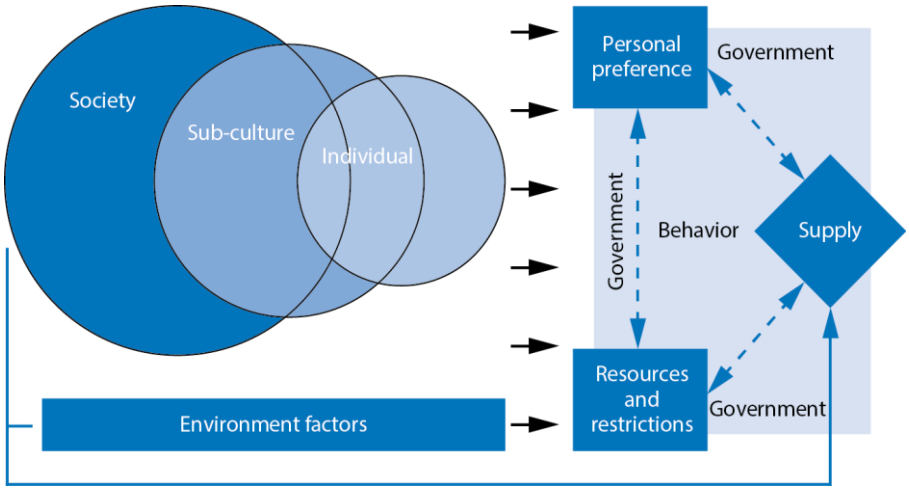

Figure 10 - Leisure behaviour model (Mulder, 2014)

4.7 Operational plan

Using several theories that have been mentioned above, an operational plan has been developed to help planning the execution of an experiment. The plan should be filled in prior to the experiment and help creating a successful experiment with the needed results.

The first step focuses on the baseline of the experiment with the subject, theoretical background, and the research questions. Other theories, like the Guest Experience Model have been integrated, using the foundation of this model, with the vision and mission for this experiment. Having a clear timeframe as well as a clear view on the end product prior to the experiment, can lead to better results.

The second step uses the theories of the DIM-ICE model and the RAMP analysis of Keith Still. Using those theories and intertwining it with the touchpoints of the Guest Experience Model of Wijngaarden ensures a complete overview of the experiment. The touchpoints of "people" correlates to the Management of the experiment since it deals with the staff members on site and how the crowd is being managed. The touchpoint "setting" correlates to the design of the experiment since it considers physical and virtual aspects that can be perceived with all senses. The touchpoint "process" correlates

to the Information given to the participants since it deals with all the supporting processes the customers must undergo before reaching the final experience.

A template can be seen below. The plan has been created and used in preparation for the two experiments. The filled in versions for both experiments can be found in the appendix 3 and 4.

Operational plan for experiments

Foundation

Subject	
Theoretical Background	
Vision / mission	
Research questions	
Hypothesis/expectations	
Materials	
Timeframe	
End product	

DIM-RAMP model / Touchpoints

Design of the Experiment	
Information given to participants	
Management of the experiment	

Route of the participants	
Area of the experiment	
Movement of the participants	
Profile of the participants	

Figure 11 - Operational plan for experiments

5. Desk research

Desk research has been done to gather a baseline of knowledge on the topic. Through this research method knowledge on the numerous guidelines in various European countries have been gathered, as well as experiments and studies that have been executed previously.

5.1 European guidelines

Within the event industry, there are numerous guidelines that refer to several safety related topics of events. The most well-known is the 'Purple Guide to Health, Safety and Welfare at Music and Other Events' from the United Kingdom (Events Industry Forum, 2014). Many countries are using this guide and it has been developed by the Events Industry Forum in collaboration with the UK events industry. The aim is to support music or similar event organisers with important information regarding safety. There are also other guidelines in other countries, which are based on their own law and research. Those safety measures can be different between countries, and it can lead to confusion about which numbers are the best. When event organisers are using those measures of the guideline, it can be a high risk, if those numbers are not correct.

Based on the desk research and information of experts, an overview of the differences has been created. It shows the key figures stated in the most used guidelines in the United Kingdom, the Netherlands, Germany, and Sweden. For the United Kingdom the 'Purple Guide' from the Events Industry Forum (Events Industry Forum, 2014), as well as the 'Green Guide' from the department for culture, media and sport have been used (Department for Culture, Media and Sport, 2008). From the Netherlands the 'Evenementenhandboek' from the 'Nederlands Handboek Evenementen Veiligheid' (NHEV) has been used (Nederlands Handboek Evenementen Veiligheid, 2019). From Germany the 'orientation framework' of the Ministry of the Interior NRW (Ministeriums des Innern NRW, 2021) and from Sweden the 'Event Safety Guide' from the Swedish Civil Contingencies Agency (Swedish Civil Contingencies Agency, 2011) have been used.

The first column compares the throughput of a door per minute and per metre. The second column shows the throughput of stairs per minute and per metre. The minimum door width is being compared in the third column and in the last column the recommended evacuation time is being displayed.

Table 1 - Guideline comparison of different European countries

Country				
UK	**82** p/min/m	**66** p/min/m (stepped surface)	Min. **0.75** m; ideally **1,05** m	**5-10** min
The Netherlands	**90** p/min/m free width of room **110** p/min/m with door angle of less than 135° **135** p/min/m with door angle of more than 135°	**45** p/min more than 1 metre **90** p/min less than 1 metre	Min. **0.80** m	**1** minute for festivals, no other time norms
Germany	1,20 m per 600 people (outdoor) 1,20 m per 200 people (indoor)	**36** to **60** p/min/m	**1.20** m	**6-15** min
Sweden	**100** p/min/m	**73** p/min/m	**1.20** m	No time norms found

Throughput of a door/bottleneck

The first column compares the throughput of a door per metre and per minute. Here, the first difference can be seen between the UK and the Netherlands. The Purple Guide states 82 people per minute and metre, whereas the Netherlands states different key figures based on other factors. 90 people can pass per metre free width per minute, if the door angle is lower than 135° outward-facing 110 people can pass, and if the door angle is 135° or higher than 135 people are able to pass per metre and minute. This comparison already shows the difference between the two countries, which can have a significant impact on the safety at events. In the German guideline, the throughput is calculated differently, so it is difficult to compare to other key figures and therefore, will be disregarded in this comparison. In the Swedish guideline it is stated that 100 people can pass per minute and metre, which is in between the key figures of the UK and the Netherlands.

Throughput of stairs

The second column compares the throughput of stairs per minute and metre. The UK states 66 people can pass the stepped surface per metre and minute, whereas the Netherlands states only 45 people if the high difference that needs to be crossed in more than one metre. If the high difference is less than 1 metre, then 90 people are able to pass per minute and metre. The Germany guidelines states that between 36 and 60 people are able to pass per minute and metre, depending on the length of the staircase, as people might get tired and slow down if the stairs are long. The Swedish guideline has the highest key figure with 73 people per minute and metre. None of the guidelines state if the key figures are related to going up or down the stairs, so it is difficult to compare the figures, as there might be a difference between going upwards or downwards on a set of stairs.

Minimum width of emergency door

Germany and Sweden have the same door width with 1.20 metre. The Netherlands recommends only 0.80 metre. The UK has the lowest key figure of only 0.75 metre but recommends 1.05 metres. This difference can have an influence on the throughput rate of the event, as less people might be able to pass the smaller emergency doors. Further difficulties could be faced by wheelchair users, as wheelchairs are on up to 81.5 centimetres wide, according to the Americans with Disabilities Act (U.S. Department of Justice, 2010) and therefore, might not be able to evacuate the premises on their own.

Evacuation time

The UK and Germany are the only countries on this list that give a recommended evacuation time, between 5 to 10 minutes and 6-15 minutes. The Netherlands only has an evacuation time of 1 minute for festival tents. In conversation with an expert from the Event Safety Institute, I learned that there are no other time norms for the Netherlands. For Sweden, there was not time stated in the guideline and further research did not give any information on this topic.

5.2 Experiment and studies

Focussing on the key figures, several experiments have focused on the “pedestrian flow through bottlenecks” (Kretz, Grünebohm, & Schreckenberg, 2006). In 2006, research has been conducted with different door widths of 40, 50, 60, 70, 80, 90, 100, 120, 140 and 160 centimetres at the university Duisburg-Essen in Germany. The researchers used 94 students and the bottleneck has been created using two cabinets that were two metres high and 40 centimetres deep. Cameras have been installed from above and from the side, but for the analysis only the footage from above has been used. This study concluded 1.77 people are able to pass a one-metre-wide bottleneck per second.

Another study has been done in 2016 focussing on the “differences in emergency escape and experimental pedestrian crowd egress through quantitative comparison” (Shiwakoti, 2016). For this study, two previous experiments have been used as comparison to a simulation. The first experiment that has been used has been mentioned above. The second experiment has been done by researchers at the Institute of Industrial science at the University of Tokyo. For both experiments, videos footage has been used and analysed. The results show a flow of around 1.81 people per second per metre. For the simulation, 100 randomly generated people and bottleneck widths of 80, 100 and 120 centimetres have been used to simulate the experiment in Germany. The results show a higher flow rate of around 1.91 people per second per metre.

Another study has been conducted on the “evacuation of crawlers and walkers from corridor through an exit” in Japan in 2006 (Nagai, Fukamachi, & Nagatani, 2006). The team has conducted two experiments, one where the participants crawled on all four to the exit and the other where they walked normally. Two cameras have been used on each side of the bottleneck for further analysis afterwards. The results show a flow of 3.30 people per second through a width of 120 centimetres, meaning 2.75 people per second per metre.

An additional guideline has been retrieved by the International Maritime Organization, stating the “interim guidelines for evacuation analyses for new and existing passenger ships” (International Martime Organization, 2002). It has been published in 2002 and the key figures are based on an analysis of fire risk. The guideline states a maximum specific flow of 1.3 people per second per metre in a density of 1.9 people per square metre. This guideline also states key figures for the maximum flow on stairs, which is 0.88 people per second per metre upwards and 1.1 people per second per metre downwards. The numbers are based on the SFPE Fire Protection Engineering Handbook (Hurley, 2016).

6. Field research

6.1 Expert session – 15th of March 2023

Using the findings of the desk research, a creative session with experts from various backgrounds has been organised. The session was executed on the 15th of March on the BUas campus. Among the attendees were experts from the Event Safety Institute, the Police, the Dutch Defence Academy, Skills Crowd Management, and a municipality advisor in the field of fire and evacuation safety. The aim of the meeting was to gather experts in the field to participate in the CSR-Lab, developed by LCB. Furthermore, the creative session was used to gather qualitative insights and information into safety at events and the usage of the various guidelines and key figures. A summary of the session and a transcript can be found in appendix 1 and 2.

Justin van de Pas facilitated the first half of the meeting, as a representative of LCB, explaining the CSR-Lab and future goals. The second part of the meeting was facilitated by me. The focus was on evacuation and the differences among the numerous guidelines in the Netherlands and other European countries. Creative techniques have been used to create a discussion among the participants and gather information from the experts regarding their usage and knowledge on the existing guidelines.

Figure 12 - Answers of questionnaire on "Which guidelines do you use for your risk analysis?"

Within the questionnaire on Mentimeter, the usage of any guidelines among the experts has been discussed. The result is that most experts are using the 'Green Guide' from the UK and the 'bgbop' from the Netherlands. The 'Green Guide' is being used for sport events in the UK and the 'bgbop' stands for 'Decree on Fire Safe Use and Basic Assistance Other Places' and is a Dutch document. Other mentions are several handbooks, the building act 'Bouwbesluit,' new publications, and the Eurocodes.

This shows the amount of information that is available for the experts, and everyone is using various sources.

"I sees legislation as rope railing that I can hold on to, but I can go left with it, and I can go right with it. You can move within it based on various factors. (e.g., subsoil of a meadow the event takes place on."
- Gerrit Vermeer (Brandweer, safety advisor)

The discussion afterwards showed that the guidelines are a recommendation and not a law. The experts unite in the fact that the key figures stated in the guidelines are based on various factors and often do not represent the reality. Measurements are often taken at only one event instead of a series of events. Therefore, the numbers are less reliable. Every event is different and has unique requirements. In conversations between the event organiser and the municipality before the event, the discussion sometimes turns political, added Daan van Eeden from the Veiligheits Regio.

"Event organisers enter the conversation with the municipality, where it sometimes gets political: then the municipality chooses the safety key figures. It is not always the case that the organisation chooses the numbers that are most favourable."
- Daan van Eeden (Veiligheits Regio Midden- en West-Brabant)

This shows that the event organiser has a wide scope when organising an event and sometimes favours revenue over safety. Then the municipality needs to intervene and ensure that the event is safe for all attendees. The base for these decisions are the key figures stated in the guidelines and therefore, it is important that those numbers are correct and reflect the reality as much as possible.

Another question during the session was focussing on the knowledge of safety related key figures of the experts. The most frequently mentioned key figures were 90 people per metre per minute and 135 people per metre per minute. Those are from the Dutch Evenementenhandboek, which the experts know well since they are working the in the Dutch event industry. Another frequent mentioned number was the 82 people per metre and per minute, since it is the number from the Purple Guide from the UK. Most experts know this number as well, as this guideline is used in other countries as well.

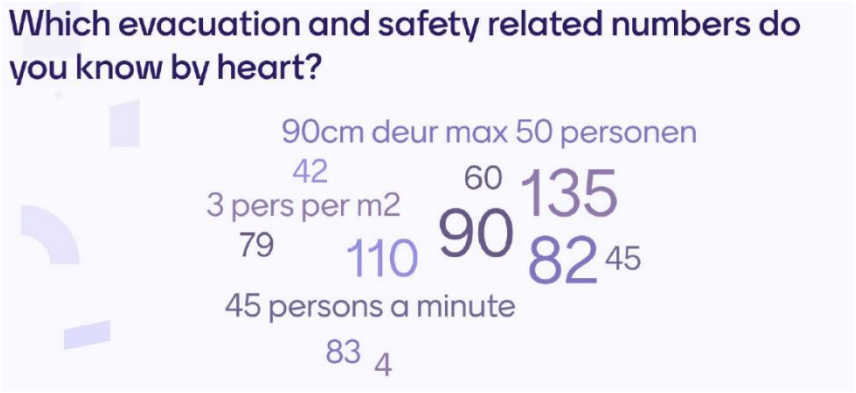

Figure 13 - Answers on questionnaire on "Which evacuation and safety related numbers do you know by heart?"

Many other key figures from various guidelines have been added to the overview during the session and a discussion started on the interpretations and importance of certain key figures.

Creating a reliable and valid experiment was discussed during the session as well. Since the CSR-Lab was only created weeks before the meeting, no experiments have been executed yet, knowledge is missing. The experts gave valuable insights. Creating an experiment comes with many variables that need to be managed, like the design, the profile of the participants and the surface of the experiment. Therefore, the experts mentioned that the key figures stated in the guidelines often do not represent various crowds, but only one type of crowd.

"We have 1 number for all types of people, while it also matters if you have certain particular target group. Older people are slower, for example."
- Mark Helgers

This suggests that the key figures only apply for certain events and not events including an older audience, disabled people, or intoxicated people. In future experiments this should be considered, but it was not relevant for the experiments organised for the graduation project, due to the limited timeframe of the project.

Another result of the expert session was to discussion about the reliability of the experiments. Since every experiment has different variables, the outcome is also influenced by those. Therefore, the decision has been made to focus on the repetition of the experiments. The first experiment will be used to create a baseline and the second experiment will be used to make them more reliable.

The session has shown that the knowledge on the safety standards varies among the experts, and it often created discussion among the experts on how the guidelines can be interpreted and applied. There is much potential to improve the information within the guidelines to accommodate certain events, target groups, and environmental influences.

At the end of the session, ideas for future experiments have been gathered and the experts shared what kind of information they would be interested in. Those were noted and will be considered by LCB when creating experiments in the next years.

6.2 Experiment 1 – 3rd of April 2023

Based on the desk research and the insight of the expert session, the first experiment has been executed on the 3rd of April 2023. Cameras have been set up to ensure further analysis after the execution of the experiment. The experiment has been planned using the newly created operational plan, based on the DIM-ICE model, the RAMP-analysis, and the Guest-Experience Model. This plan ensures all aspects are considered and a unique experience for the participants has been created.

Design

The design of the first experiment can be seen below. This design has been chosen because it includes all needed aspects that needed to be researched. The four doors had a different door width. Doors 1 and 2 were two metres wide, doors 3 and 4 were one metre wide. The participants were able to walk around door 3, to create a larger group. The designated route has been marked with barricades to lead the students on the right path. The cameras have been installed in areas that are most important for this research.

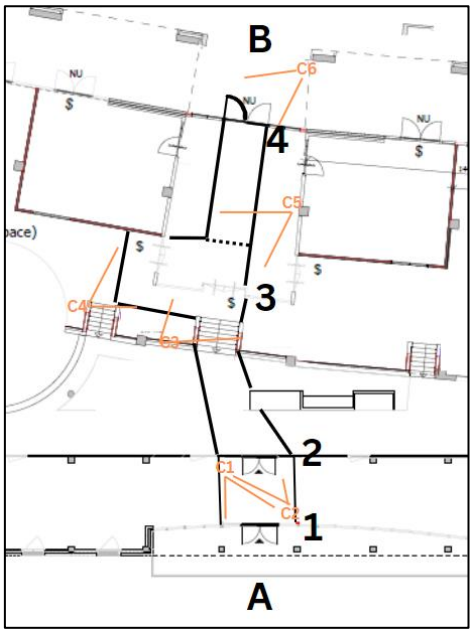

Figure 14- Design of experiment 1

Information

One week before the experiment day, an informative presentation has been given to the students where the reason of research and the objective of the experiment has been explained. The first planning for the experiment was shared and any questions by the students have been answered. The aim of this presentation was to give the students already insights into the topic and create positive anticipation towards the experiment day.

On the day of the experiment, the participants were given a presentation on the concrete planning of the day. The drawings of the experiments have been shown and shortly explained, so the students are aware of what is expected of them and what they can expect during the day. To create a positive setting, the students were greeted with drinks and a snack and during the break, free soft drinks were provided. The aim was to motivate the students to participate in the experiment with enthusiasm and take it seriously.

Management

During the experiment, the research team, was made up of three employees of LCB, another graduation student at LCB and me. Each member has been briefed on the experiments, their tasks, and the reason of research before the start of the experiment. Every member of the research team was located on their designated location during the experiment and took measurements by counting people passing their marked line. The students were given instructions by the research team.

Route

The route that the students would take has been marked before the execution of the experiment, with arrows displaying the expected density along the route. Green shows a low density with up to two people per square metre. Yellow means between 2 and 3 people per square metre. Red means three or more people per square metre. This division has been made based on the research done by Keith Still (Still, 2018). This way, the expected bottlenecks can be distinguished beforehand and either neutralized or more focus can be put on it during the experiment.

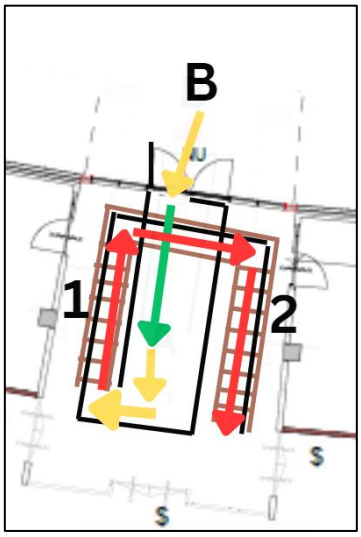

Figure 15 - Route of experiment 1

Area

The area of the experiment was the Innovation Square in the Frontier Building of the Breda University, as well as the staircase next to the Innovation Square, from the ground floor up the stairs to the third floor. As gathering zones, the area in front of the entrances has also been used. The entrance area at the staircase has 49,2m², the Innovation Square has around 32.3 m² and the entrance on the other side has 11.1 m².

Movement

The students arrived between 13:30 and 13:50 at the Sports bar on campus, coming from various directions. After the introduction, all students and the research team moved to the starting point at area A at around 14:25. During the experiment, the students walk and ran through the Innovation Square to area B and back to area A. After experiment 1, the students walked back to the Sports bar for a small break. For experiment 2, the students walked to area B and were asked to walk and run up the stairs to the third floor and back down to area B. After the second experiment the students walked back to the Sports bar and left the campus in various directions.

Knowing the movement in advance, helps coordinating the staff and inform the crowd. Specific arrangements can be made, like closing off certain areas and informing nonparticipants about the expected crowdedness in certain areas in certain timeframes. In this experiment, other students and staff working at the Innovation Square have been informed about the experiment and the timeframe, where it will be noisy.

Profile

The participants were second year Live Music and Dance Events students from Breda University of Applied Sciences. The ages range from 18 to 25 years. The students were familiar with the surroundings of the building, but not the specific design of the experiment. They were all fit and mobile to execute the requirements of the experiments.

Knowing the profile of the crowd, can help when managing the crowd. Each crowd is different and has an impact on the experiment and the experience for the participants.

6.3 Experiment 2 – 24th of April 2023

Design

A similar design has been chosen for the second experiment, since the focus is on validating the data that has been collected during the first experiment. Therefore, the design has been changed to be only in the staircase next to the Innovation Square, using the stairs and the door leading outside. The door was one metre wide for the first experiment. For the second experiment the width differed from 0.8 metre to 1.2 metre to 1.4 metre. The experiments focus on the impact of the door angle, the door width, and the throughput of the staircase. Cameras have been installed in the most interesting areas as well, to ensure further analysis after the execution of the experiment.

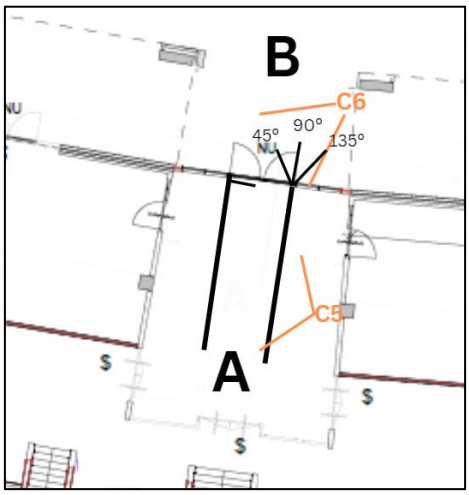

Figure 16 - Design of experiment 2

Information

A week prior to the second experiment, information has been shared with the students using their Teams channel. They received information about the planning, the location, and the duration of the experiments. For the experiment day, a presentation has been prepared with drawings, so the students are aware of what is expected of them and what they can expect during the day. To create a positive setting, drinks and a snack have been prepared for the break. The aim was to motivate the students to participate in the experiment with enthusiasm and take it seriously.

Management

For the experiment, the research team, was made up of three employees of LCB and me. Each member has been briefed on the experiments, their tasks, and the reason of research before the start of the experiment. For communication among the research team, a WhatsApp group has been set up. When entering the meeting point, the research team has taken the attendance of the students, to create an overview on the number of participants.

Route

The route the students would take has been marked on the planning as well, using the same technique as in the first experiment. This way, the expected bottlenecks can be distinguished beforehand and either neutralized or more focus can be put on it during the experiment.

Area

The area of the experiment is the Frontier building of the Breda University of Applied Sciences. It has been organised at the staircase next to the Innovation square, from the ground floor up the stairs to the third floor, as well as outside in front of the entrance to the staircase. The staircase has 49,2m².

Movement

The students arrived at 12:45 at the Sports bar on campus, coming from various directions. The first experiment was planned to start at around 14:10, after a session in the Sports bar. The students would walk from the Sports bar to the starting point at area B, in front of the entrance to the staircase. For the first small experiment they would walk and run up the stairs to the third floor of the building and back down to area B. For a short break, the students would walk back and forth from the Sports bar. The second and third experiments would be executed in the staircase, area A. They would walk and run outside and go back inside to repeat it a few times. Afterwards they would walk back to the Sports bar and leave the campus in various directions.

For this second experiment, other students on other floors and staff working at the Innovation Square have been informed about the experiment and the timeframe, where it will be noisy.

Profile

The participants were second year Live Music and Dance Events students from Breda University of Applied Sciences. The ages range from 18 to 25 years. The students were familiar with the surroundings of the building, but not the specific design of the experiment. They were all fit and mobile to execute the requirements of the experiments.

6.4 Interview – Armin Seyfried

An interview with the crowd safety expert Armin Seyfried from the research centrum in Jülich, Germany, has been arranged. He studied at the University of Wuppertal and started working at the research centre in 2004. Since then, he has been working on improving safety concepts with the help of experiments. He also gives lectures at the University of Wuppertal about computer simulation for fire protection and pedestrian traffic. The aim of the interview was to gather insights into the planning, execution, and analysis of an experiment. Furthermore, questions about crowd safety and crowd behaviour have been discussed (Seyfried, 2023). The German transcript and the English summary of the interview can be found in appendix 6 and 7.

When talking about the guidelines in different European countries, Armin Seyfried mentioned that he is not aware of other guidelines. He focusses on the ones in Germany, but he is positive that there are differences. In his opinion, the guidelines are often not completely reliable, since some data is outdated, and new technology has been developed to improve the data (Seyfried, 2023).

The execution of an experiment is a lot of work, he mentioned, since it takes around one year per person to prepare a reliable and insightful experiment. The technical aspects play and important role, as well as the selection of a target group. The analysis of the data also takes a long time since it is being checked by hand and corrected. The results are being published on the website of the research centre and are hopefully used by experts in the event field to improve their knowledge on crowd safety and to create safer events in the future (Seyfried, 2023).

When talking about crowd behaviour he mentioned that they tried to minimize the effects of the Covid-19 pandemic during the experiments. They forced the target group to be in highly dense crowds, to recreate the behaviour pre pandemic. However, he is sure the effects of the pandemic are slowly fading away and crowds are staring to behave normally again (Seyfried, 2023).

Further information on the topic has been sent to me since the gives lectures on this topic and has much valuable information. This information has been used for further desk research, due to the missing execution of the second experiment.

6.5 Interview – Syan Schaap

An interview with Syan Schaap from the Event Safety Institute has been arranged. He is the director and founder of the institute and give advice to municipalities and safety regions on safety management, event policy and crowd management at events. The aim of this interview was to analyse and confirm the data gathered during the first experiment. Furthermore, the aspect of crowd behaviour during an evacuation has been discussed (Schaap, 2023). The transcript of the interview can be found in appendix 8.

After sharing and explaining the results of the first experiment, Syan saw similarities with the guidelines and key figures he uses during his work. He mentioned that the experiment was only executed with a small target group and that the number would differ, if the density was higher before the bottleneck. He shared that the speed of the evacuating people slows down by 60% if the density is higher than three people per square metre. This effect was not visible during this experiment, due to the number of participants (Schaap, 2023).

When talking about the results of the second experiment, Syan mentioned the low difference between taking the stairs upwards or downwards. It is similar to the guidelines and key figures he uses during his work. The main striking aspect was the reduction in speed when going up the stairs, which might be explained with fatigue, due to the gravity (Schaap, 2023).

When comparing the results to other studies he mentioned that the results are similar and that it is important to give context to it. The experiments were executed in optimal conditions, with physical able target group, an even ground, good lighting, no real dangers. All the aspects have an influence on the speed of the evacuating people. The results of the experiments might differ from real-life evacuations, due to these factors. Therefore, it is important to keep those in mind when analysing the data. When comparing the results to the guidelines, he advised to use the safest option, meaning the 82 people per metre per minute through a bottleneck from the guideline of the UK and the 45 people per minute per metre on stairs from the Dutch guideline. A combination of those guidelines is the best option, since following only one guideline would lead to too high numbers on the stairs or the bottleneck (Schaap, 2023).

When talking about the behaviour of the crowd during an evacuation, he mentioned that there are several factors that have an influence on the behaviour of the crowd. There are different models that have explained these factors, like the ‘Escape Safety Model.’ However, those do not give enough information. A better option is to use studies and field research, to understand what aspects have an

impact on the speed of the evacuating people. During emergency situations, people often go back their primal instincts and are not able to think critically. Other times, they are able to help each other and behave in a social way. The 'social identification model' is often used to understand the crowd behaviour. There are three ways in which people react to an emergency: fight, flight, or freeze. Around 80% of a crowd needs guidance, 10% of the crowd act very adequate and the remaining 10% of the crowd does not accept this situation. Therefore, it is important to react to each group of people adequately, since every target reacts differently in different situations (Schaap, 2023).

7. Findings

7.1 Experiment 1

During the execution of the experiment, measurements have been taken by the research team by counting students passing a specific section. Due to technical difficulties and human failure the measurements were not reliable for further analysis. Therefore, the camera footage has been used for the continuation of this research project. The footage has been saved online and was analysed by slowing it down and counting the people crossing the specific section by hand within one minute.

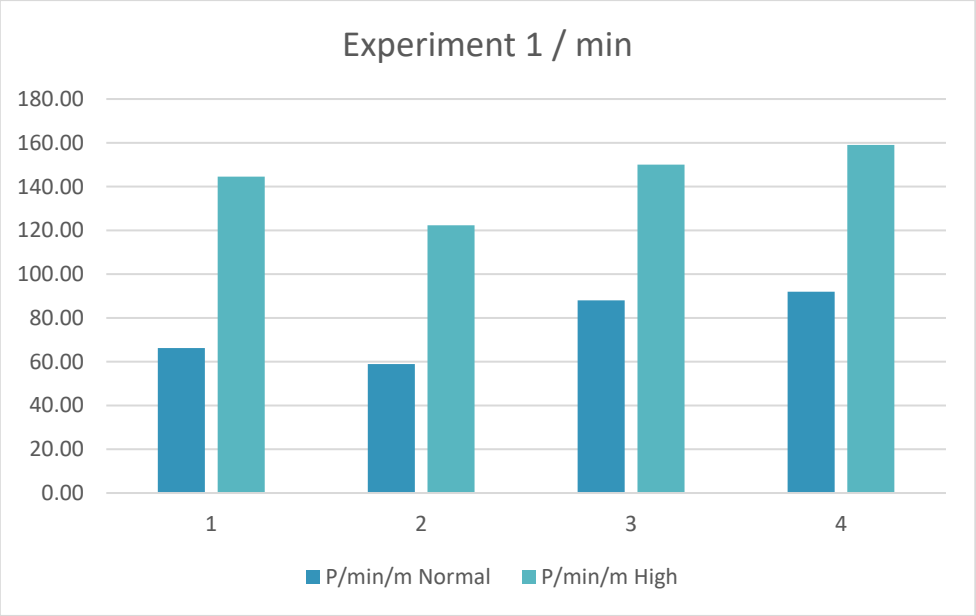

Figure 17 - Results of the experiment on the throughput of a door

The analysis of this experiment was focused on the flow rate of a one-metre-wide door, and it has shown that in normal urgency between 59 and 92 people can pass per minute. The difference between the doors can be explained by the design of the experiment. Doors 1 and 2 were two metres wide with no further obstacle in the area. Door 3 was one metre wide, and the participants were asked to walk around the corner and through the same door again, in a circle. This could have had an influence on the flow rate of this door. Door 4 was one metre wide as well but showed the highest flow rate with 92 people per metre and minute, due to the participants being in a dense crowd at door 3. People were able to move to the last door quickly. Combing the results, 76 people were able to pass per minute per metre in normal urgency on average.

This difference also shows during the experiments with a high urgency. The participants were asked to run through the experiment's design, by imagining an emergency. Here, between 122 and 159 people were able to pass one metre per minute. Door 4 showed the highest flow rate with 159 people per

metre and minute, due to the high density at door 3 and accessibility for the participants. Combining the results, 143 people were able to pass per minute per metre in high urgency on average.

The difference in normal and high urgency can be seen clearly. The participants were around two times faster than with a normal urgency. The biggest difference can be seen at door 1, with 2.18 times faster, due to the high motivation of the participants and accessibility of the door. The lowest difference can be seen at door 3, with 1.76 times faster, due to the congestion and high density around the door, which slowed down the movements of the participants. Combining both urgencies, a total average of 110 people per minute per metre can be concluded.

The second experiment focused on the flow rate of a staircase. Measurements have been taken on each set of stairs leading to the third floor, two flights of stairs per floor, resulting in 6 flights of stairs from the ground floor to the third floor. This experiment was also executed in normal and high urgency, as well as upwards and downwards.

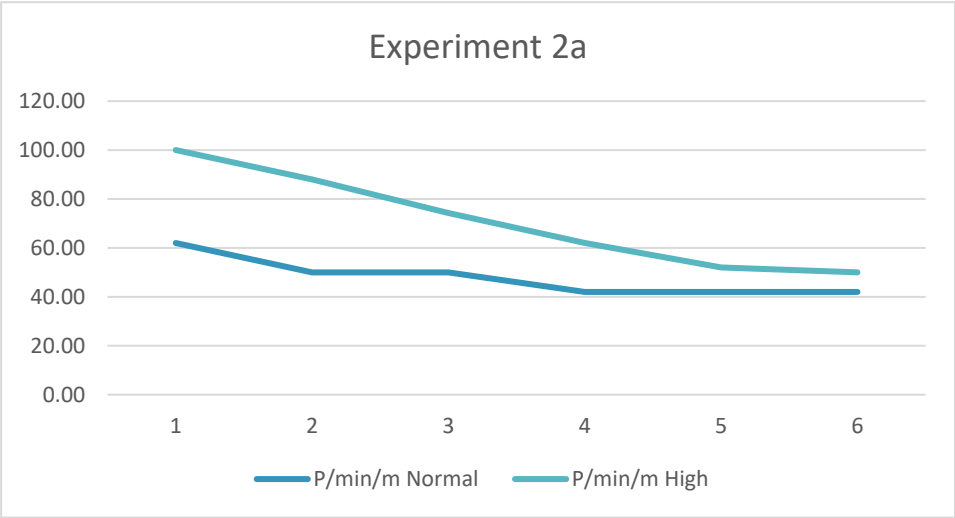

Figure 18 - Results of the experiment on the throughput of stairs upwards

In experiment 2a, in normal urgency between 42 and 62 people were able to pass in one minute upwards. The highest being the first set of stairs with 62 people per minute and the lowest being the last three stairs, which shows the speed of the participants has slowed down, due to possible fatigue. In high urgency similar results can be seen, with the highest being the first set of stairs with 100 people per metre and a rapid decline to the last set of stairs with only 50 people per minute. In normal urgency, the speed between the first set of stairs and the last set of stairs declined by 0.68 times and in high urgency the participants were half as fast on the last set of stairs compared to the first set of stairs. This shows the impact of the length of the staircase on the speed of the participants. The longer the staircase, the slower the participants. On average 48 people were able to pass upwards in one

minute in normal urgency and 71 people in high urgency. Therefore, the total average of this experiment results on 59 people per minute per metre taking the stairs upwards. The concrete figures can be found in appendix 5.

In experiment 2b, between 58 and 64 people passed in one minute downwards in normal urgency. The highest being the first set of stairs on the third floor. The speed of the participants barely slows down during the experiment and is constant around 53 people per metre on the last four flights of stairs. In high urgency, between 76 and 58 people per minute were able to pass. However, no clear trend can be seen, due to the variation of numbers on each set of stairs. On stairs 6 the participants have the same speed as in normal urgency, but then increase the speed on stairs 5 and 4, but slow down again on the next set of stairs and afterwards it is consistent until the ground floor, with around 60 people per metre. Only on the last set of stairs the participants sped up again until 70 people per minute.

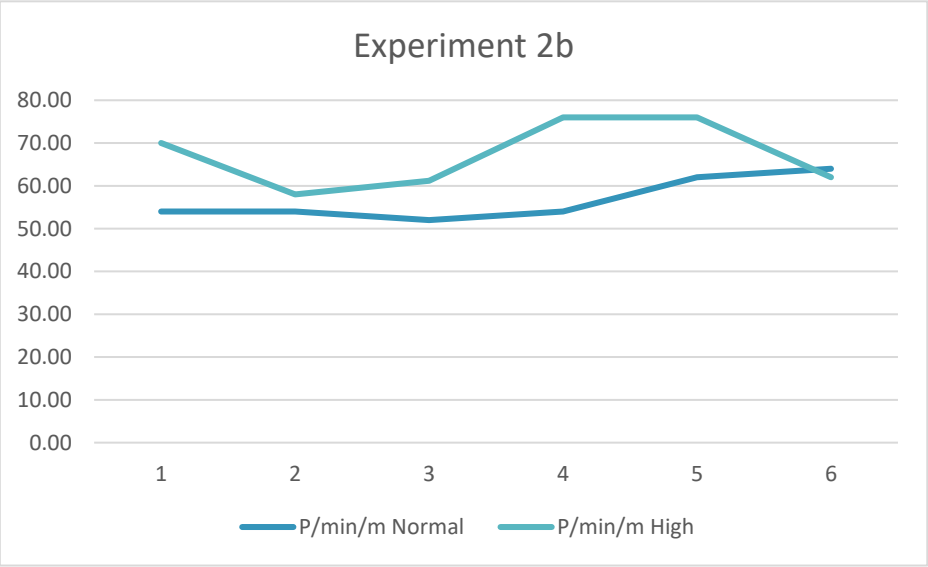

Figure 19 - Results of the experiment on the throughput of stairs downwards

This suggests that the length of the stairs only has a small impact on the speed of the participants, due to the consistent speed in the middle of the staircase. It might be possible that a longer staircase slows down the speed even more, due to fatigue, but it has not been seen in this experiment. On average 57 people were able to pass downwards in one minute in normal urgency and 67 people in high urgency. Therefore, the total average of this experiment results on 61 people per minute per metre taking the stairs downwards. The concrete figures can be found in appendix 5.

7.2 Experiment 2

Due to unforeseen circumstances the experiment was not being executed. The preparation has been done in detail and the event has been made mandatory for the participants. 65 students have been invited but only 17 students showed up. Information has been shared beforehand and benefits for the students have been arranged. However, only a small number of participants showed up on the experiment day. Therefore, it has been decided to not execute the experiments. Efforts to reschedule the experiment were not successful, due to limited time. Therefore, it was not possible to validate the data gathered during the first experiment.

The planning of executing a survey after the second experiment were also cancelled, due to the missing execution of the second experiment. The students seemed to be not enthusiastic about participating and a survey would not have given any valuable information for this research. Therefore, it has been decided to disregard the survey and focus on desk research and field research through expert interviews.

8. Analysis

To compensate the missing data of the second experiment day, more desk research has been done. The focus was on experiments that have been done previously on the same topic. Numerous experiments have been done over the years on the topic of emergency evacuations, pedestrian traffic, and the crowd behaviour during those situations.

8.1 Comparison to other studies

When comparing the above-mentioned studies and guidelines with the results of the experiments, executed on campus, the similarity becomes clear. These studies mentioned above go beyond what is described here, however the sections that are comparable to this experiment are the main emphasis. An overview can be found in appendix 5.

The studies focusing on the throughput of a bottleneck, conclude key figures between 79.8 and 165 people per minute per metre. Three of the studies have lower results than our experiment, however, they are still very close to each other. Only one study has a much higher result, with 165 people per minute per metre. Therefore, the result of the experiment, 110 people per minute per metre, is close to the average of the findings of the other studies. However, since most experiments do not include any disrupting factors, the result should be viewed as the maximum egress rate. The guidelines provide key figures between 82 and 130 people per minute per metre. Since the guideline should provide key figures that ensure the most safety, the results of the experiment are too high. The disrupting factors that slow down the evacuation time need to be included in the guideline and therefore, a lower number is advisable. In conversation with Syan Schaap from the Event Safety Institute, it was concluded that the most advisable guideline to use is the one from the UK, with 82 people per minute per metre since it ensures the most safety.

Looking for research on the throughput of stairs, not much information has been found. Most studies focus on the speed of the participants. The only study that has been found from the international maritime organisation concludes a throughput of 52.8 people per minute per metre when going upwards and 66 people per minute per metre going downwards. Therefore, the results of the experiment, 59 and 61 people per minute per metre, is in the middle of those results. The guidelines provide key figures between 45 and 90 people per minute per metre. Due to the safety requirements the number used should be lower than the results of the experiment. The disrupting factors have an influence on the speed of the evacuating crowd and therefore, the guideline with a lower key figure should be used. In conversation with the expert from the Event Safety Institute, it was concluded that

the most advisable guideline to use is the one from the Netherlands, with 45 people per minute per metre since it ensures the most safety.

8.2 Crowd behaviour

The behaviour of a crowd during an evacuation has been analysed in different theories, experiments, and articles. One theory that analyses the behaviour of an individual and what influences this behaviour is the model of Knulst (Mulder, 2014). It focusses on the leisure behaviour, but it can also be applied to the behaviour during an evacuation. The society, the sub-culture, and the individual itself influences the behaviour of a person, through norms, values, traditions, and motivations. If the society values social aspects, the behaviour might change to helping other people during the evacuation instead of behaving as an individual. This aspect can also be found in the 'analysis model escape safety' of Kobes and Oberijé (Kobes & Oberijé, 2010). It analyses the different characteristics that influence the behaviour in case of a fire. One aspect being the human characteristics, which can be divided into personal, social, and situational characteristics. Personal characteristics meaning the person's profile, knowledge, and experience, which correlates to the individual aspect ok Knulst. The social characteristics focus on the social relationships and the role responsibility, which correlates to the society and sub-cultures of Knulst. All these aspects together create the personal preferences of a person, which would be evacuating safely. The environmental factors are beyond human influence, meaning the location and other time-spatial constraints. This correlates to the building characteristics and fire characteristics of the 'analysis model escape safety,' like the layout and the size of the building. The resources and restrictions of Knulst focus on the four main capitals. Physical capital focuses on the traits that make up a human, whereas cultural knowledge emphasizes the knowledge and experience the individual possesses. Both can be connected to the personal characteristics of the 'analysis model escape safety' again. The social capital focuses on the social relations of the individual and therefore correlates to the social characteristics. All these aspects have a great influence on the behaviour of the individual and can be analysed using the two models.

Experiments on this topic have also been conducted. In 1951 Alexander Mintz analysed the non-adaptive group behaviour. During the experiment 15 to 21 people were asked to pull out cones out of a glass bottle, which was hanging from a string in the bottle and each participant held a string in their hand. The bottleneck was designed in a way that only one cone could pass through at a time. Therefore, the participants needed to collaborate to take out all cones one at a time instead of creating a congestion. The motivation of the participants was increased using prizes. After 42 experiments with 26 different groups, the results show the development of a congestions at the bottleneck in most experiments, resulting in no one being able to pull out their cone. In other experiments, the

participants were not given rewards and were able to pull out their cones faster using communication among the group and hinder a congestion at the bottleneck. This experiment would suggest that cooperative behaviour among the participants leads to “success and is rewarding to [the] individual[s] as long as everybody cooperates (Mintz, 1951).” However, if participants start to behave in an uncooperative way, it could lead to disaster, due to people blocking the exit and push each other out of the way to exit as quickly as possible. The experiment showed that a small reward or an advantage for one person in the group, makes an uncooperative behaviour more likely and therefore, slowing down the evacuating process (Mintz, 1951).

Other research on this topic, however, suggests a different result. It is difficult to assume that if there is competitive behaviour it would slow down the evacuating process. Further research from the research centre in Jülich has shown that it is dependent on the corridor width leading to the bottleneck. A high motivation leads to high speeds in the beginning, but the speed slows down at the bottleneck, due to the limited space available. If the motivation is lower, the speed is also lower in the beginning, but at the bottleneck itself the speed is slightly higher, due to the lower density at the bottleneck. This research has shown that a broad corridor leading to the bottleneck encourages people to behave competitively, due to the participants forming a semicircle around the bottleneck. More people are closer to the opening and have a higher motivation to behave competitively to exit as quickly as possible. By contrast, if the corridor to the bottleneck is smaller, people are already in a ‘queue-like’ formation. Therefore, only a few people compete to enter the bottleneck at the same time, which increases the speed of the evacuation people (Adrian, Seyfried, & Sieben, 2020).

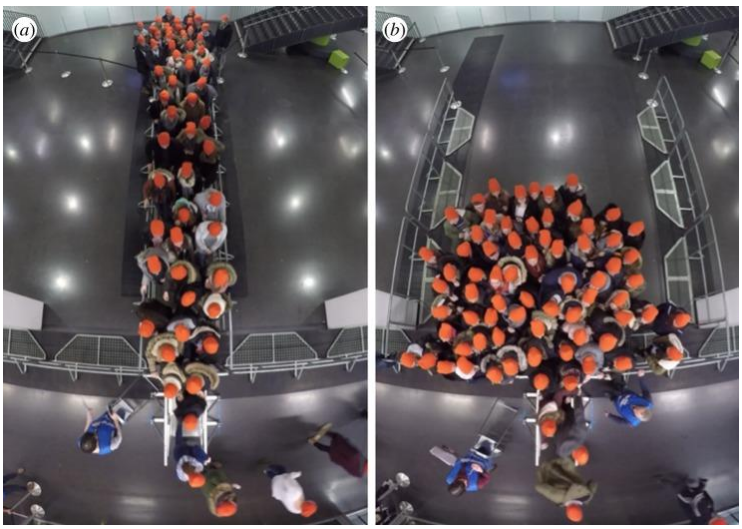

Figure 20 - Experiment design (Adrian, Seyfried, & Sieben, 2020)

The design of the area in front of the bottleneck can have an influence on the perception of the participants in the situation. A wide corridor with people forming a semicircle, the participants expect the situation to be less equal and unfair, whereas a small corridor encourages people to stick to the social norms and wait for their turn. People feel more comfortable in an orderly situation. Therefore, it is important to ensure good constructions in front of the bottleneck, so a crowding can be avoided.

If people notice, the exiting process is unfair, they are more likely to push and behave uncooperatively (Sieben, Schumann, & Seyfried, 2017).

Overall, it can be said that uncooperative behaviour slows down the evacuating process at the bottleneck. However, it depends on each situation and design of the bottleneck. People are more likely to push each other if they experience unfair treatment. Especially during an emergency people are less likely to think objectively and are less likely to cooperate with each other if there is a motivation to escape.

9. Recommendations for LCB

Based on the research, recommendations can be given to the Logics Community Brabant. Since the CSR-Lab opened only recently and these experiments were the first to be executed, there is much space for improvements.

One recommendation is to create a strategy for the planning process of an experiment. During this project, a start has been made with the operational plan. In the future, this plan needs to be optimized to the needs of LCB and the experiments.

Another recommendation is the usage of better cameras, since during these experiments only GoPro cameras have been used. LCB is collaborating with DCM and already has two cameras set up on campus. More valuable and reliable data would be collected when using those, like the walking speed and the density. The software of DCM is continuously being developed and improved and might support the research team during the analysis of the experiment in the future.

10. Conclusion

The aim of this project was to "*create better insights into the current safety standards and crowd behaviour during evacuations in the Netherlands*." To answer this questions, desk and field research has been conducted. The desk research has shown that there are differences between the safety guidelines in different European countries, especially in the throughput of a door and the stairs. Based on the desk research, a creative session with safety experts from various fields has been organised to discuss the findings and gather input for the upcoming field research. Outcome if the creative session was that even the experts were unsure about the differences and valuable information for the experiments have been gathered.

Throughput of a door

Valuable data has been collected during the experiment, executed on the 3rd of April 2023 on campus of the Breda University of Applied Science. Using 52 students as participants, concrete data has been collected on the throughput of a door and stairs in normal and high urgency. The results show that up to 110 people can pass a one-metre-wide door in one minute on average. This is the maximum rate, due to the missing disrupting factors. Comparing the results to other research and the guidelines, a lower rate should be considered, due to many disrupting factors. Therefore, the 'Purple Guide' from the UK with 82 people per metre per minute should be conserved as the most accurate.

Throughput of stairs

The results of the experiment focussing on the throughput of stairs, suggest an average of 60 people passing per metre per minute. This result should also be regarded as the maximum rate, due to the missing disrupting factors. Comparing this to other research and guidelines, a lower rate should be considered. Therefore, the 'Evenementehandboek' from the Netherlands with 45 people per metre per minute should be considered as the most accurate.

Crowd behaviour

Regarding the crowd behaviour, it is difficult suggest a most desired behaviour, due to the unpredictability of people's behaviour during an emergency. Research has shown tendencies, where uncooperative behaviour slows down the evacuation time. However, this highly depends on the profile of the people, the design of the bottleneck and the circumstances of the situation.

End product

As a result of this research, an infographic, including a knowledge clip and a 1-pager essay, has been created, which highlights the most important insights. It can be found on the website of the Logistics Community Brabant.

11. Reflection

At the beginning of this project, I was very unsure about the process and what is expected of me. Due to my knowledge, I earned during the minor in crowd management, I already had an idea of the topic. However, it took me the first few weeks to get a grasp on the topic and the way of working at LCB. Every company works differently and the open atmosphere at LCB helped me getting comfortable. I was able to ask questions and suggest ideas for the project.

Once I got a grip on the project, I started my desk research and found much information, so it was sometimes a little overwhelming. I first struggled what to include in this project and my supervisors helped me in finding a good option. They encouraged me to focus on the process of the evacuation, instead of different aspects. This gave me confidence and helped me finding more relevant data I could use for the project.

The preparation for the expert session was a very interesting phase, since I rarely organise meetings with experts in the field. I was unsure of what is expected of me during the meeting and after a meeting with my supervisors, they gave me very constructive feedback on my first planning. I was able to implement their feedback and create an interesting and creative session for the experts. During the session I was very nervous, and I believe that an even better preparation on my side, would have made it even better. However, I was able to gather the data I needed to continue this project, which I am very proud of.

The preparation of the experiments took a long time, which made me nervous. There were many factors that needed to be considered when executing an experiment and therefore, we had several meetings to discuss this process. In the end I was able to create good experiment that delivered the needed data, and my supervisors were also happy with the execution of the experiment and the results. During the experiment small changes has to be made, which made me nervous, but everything worked out in the end, due to good teamwork among the research team.

The second experiment was planned in a similar way as the first, but unfortunately the needed students did not see the importance of this project. We informed the students beforehand about all needed information and even organised prizes for them to win during the experiment. Only a few students showed up on the experiment day and I was very discouraged since I was not able to gather more data for the research. My supervisor tried to encourage me to keep going and find a different approach. It did everything I could, so it was not my fault that the student did not show up. That is what working in the event and service industry is like, people sometimes do not show up and you have to improvise. This has shown me that I am able to overcome these challenges.

After the discouragement with the second experiment, I has a meeting with my supervisor, and we agreed that I could do more desk research and interview experts to still be able to validate my data from the first experiment. I was able to gather much data and during the interviews with the expert from Germany, I received many studies and other experiments that have been conducted over the years. I was again a little overwhelmed by the amount of information I gathered, but it got easier, since I knew what kind of information I was looking for. I quickly notices similarities between different sources, which showed that I was on the right path. The interview with the expert of the Event Safety Institute, I was able to validate my data, which I was very glad about. He was very impressed with my results and explained that my results are close to what he expected from my experiment. Using all the data I collected I was able to develop a knowledge clip and deliver it to my supervisors.

All in all, I have learned a lot about during this project. I was working at a new company and realize that I am the only one responsible for the outcome of this project. At first, I was very unsure about this whole project, but was encouraged by my supervisors. They expected results and this motivated me to work on the project. I also believe that I could have done a little better in certain parts, because I lost motivation in the middle of the project, but I was able to motivate myself again, since my goal was to graduate this summer with my friends. Overall, it was an amazing experience to work on your own project and take on responsibilities. Thanks to my colleagues and supervisors I was able to finish this project and improve my knowledge event more than over the last seven semesters.

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