

Pedestrian Evacuation Planning for Major Events – a New Approach Combining Planning Aspects and Human Factors

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1 ABSTRACT

People's safety and security in urban space has a high priority for planning decisions. Especially at major events pedestrian planning aspects play a decisive role for associated evacuation scenarios. A well-developed urban design of spatial environments, with its escape routes and infrastructure on-site, is consequently most important for a fast evacuation.

The research project REPKA (Regional Evacuation: Planning, (K)Control, and Adaptation), funded by the German Federal Ministry of Education and Research, focuses on open space evacuation of major events, especially in case of national soccer matches. The soccer stadium of the 1st FC Kaiserslautern/Germany (up to 50.000 visitors), located in the inner city with a difficult topography, is centered in the project. First project results show that there are two determining factors to be regarded in context of pedestrian evacuation planning: a) urban design of escape routes in the event's surroundings and b) human factors, like socio-psychological mechanisms on the behavior, environmental perception and orientation of crowds under stress. The combination of these two factors, missing in research on open space evacuation until now, is discussed in this paper. Hence, in the research project REPKA, a spatial analysis was done to identify physical characteristics of escape routes and infrastructure. In addition, research in literature, standardized interviews (with visitors and security services) and observations concerning human factors were conducted. It became evident that different guidance systems (guidance staff, signage, new technologies) are essential for effective use of existing escape routes and a fast evacuation. Totaling, the results reveal that a well-regulated evacuation depends on a well-developed urban design combined with a guidance system including human factors. By this, evacuation time is reduced and thereby people's safety is improved.

This paper aims to make a contribution to a new holistic approach in the field of pedestrian evacuation planning. Moreover, the findings have consequences for interdisciplinary approaches like modeling of pedestrian flows in computer evacuation simulation.

2 INTRODUCTION

At present, mass events are continuously becoming more popular and take place more frequently. Security of attendees is of prime importance, but often not assured. Perilous situations can arise at any time when many people get together in a narrow place. Referring to the Hillsborough Disaster in Sheffield 1989, for example, or recently the Love Parade in Duisburg, Germany 2010, when too many people surged into a place already overcrowded. As a consequence, many people died and hundreds were injured because of too much pressure. There are a lot of other risks and accidents, which necessitate the breaking off or even the evacuation of a mass event. These may be a fire, bomb threat, technical faults or health hazards because of climatic conditions (heat, storm). There is a lot of research on evacuation of buildings, because the planning of escape and emergency routes are part of preventive fire protection and corresponding regulations. Furthermore, various simulation models regarding flight behavior during evacuation of buildings have already been developed (e. g. Shi et al. 2009, Waldau et al. 2003 or Xiaoping et al. 2008).

It is not assumed that visitors are out of danger after they have left the building in which the event was taking place. Not every venue of a mass event is outlying a city center and easy to access for arriving emergency services, such as firefighters, police and ambulance crews. Depending on the kind and extent of the threat or damage, it is necessary to bring visitors further away to safety. However, existing research on evacuation of buildings provides only first benchmarks for open-air events or crowds in public space. This is because "the movements of large number of people are distinctively different in public buildings as opposed to public event venues such as theatres, stadiums, open-air stages, etc." (Waldau et al. 2003, p. 308). For a spatially wide-ranging evacuation of mass events there is a research gap and therefore there is assumed to be a gap in security.

In case of various emergency situations or sudden break-offs of events, people have to be guided adequately for several reasons. Visitors have to be guided in order to avoid perilous situations and accidents within the mass of people, when the density of the multitude of people becomes a threat. They also have to be guided in order to get them to assembly points in a safe place. By splitting off the crowd, emergency access routes can be kept free. This is important, especially in a closely built-up environment, where evacuees stream into a public place with a lot of traffic circulation. The main stream of visitors moves towards the access route of rescue services, who get to the venue time-delayed. At soccer matches perilous situations can additionally arise when hostile fan groups meet each other.

3 INFLUENCING FACTORS ON FLIGHT BEHAVIOR

3.1 Urban design of escape routes

One dominating factor to guarantee a safe evacuation is the urban design of escape routes. Here, it is possible to take influence on the construction of the event’s surroundings. So, the planning of elaborated escape routes is the precondition for a safe evacuation. In this research, the escape routes in public space, beyond the property boundaries of the event (e. g. a soccer stadium), are regarded. There are a lot of laws, standards and regulations (e. g. public assembly by-law, state building codes, fire regulations, etc.) concerning the design of escape routes inside the building and the outdoor area within the property boundaries. But what happens after the people have left the venue? People have to be guided controlled away from disaster as far as possible in order to prevent new risks arising from the crowd itself.

Important characteristics of well-designed escape routes are already known. Partly they can be transferred from the broad field of building evacuation standards to open space evacuation in combination with some extra aspects. The aim is to accelerate the pedestrian stream’s speed and to raise the quantity of people getting away from disaster as safe as possible. Helbing et al. (2000, p. 489), for example, pointed out: “Improved outflows can be reached by columns [intended obstacles] placed asymmetrically in front of the exits, which also prevent the build up of fatal pressures.” Also the barrier-free design of environments is often underestimated. Besides slowdown effects, handicapped people could become active hindrances in the pedestrian flow. The following table shows the most important aspects for a good urban design of escape routes and their consequences for the pedestrian flow (table 1).

Urban design aspects	Consequences for pedestrian flow
Path widths	Determinate the pedestrian flow rate
Soil conditions	Potential risk of stumbling
Barrier-free design	Handicapped people can hinder a pedestrian stream
View-shafts	Orientation and perception of the optimal route away from danger (as safe and fast as possible)
Lighting	Orientation and perception of the optimal route away from danger (as safe and fast as possible)
Intended obstacles	Intentionally positioned obstacles to avoid bottlenecks

Table 1: Urban design aspects and their consequences for the pedestrian flow.

Not only the urban design in its constructional character is an important fact to help people to get away, but also the equipment of public space with emergency signage. After identifying the constructional possibilities to accelerate the pedestrian flow, it is now indispensable to know how people exactly react and behave in case of disaster. As consequence, the question is raised how human factors determine the requirements for urban design.

3.2 Human factors

A mass of people always consists of small or large groups of people. Especially attendants of mass events mostly visit the event in company of friends or family members. They stay together during the event and even travel to, arrive at and depart from the venue frequently together. Therefore, social groups within crowds have to be considered to understand and explain the crowd behavior. Research about crowd dynamics confirms that mass dynamics cannot solely be explained by the behavior of single members of the

crowd. Individual persons in turn are influenced by other individuals and groups, e. g. how they notice and act on signpost or on other instructions and if they decide for or against the usage of a certain route.

Different factors have an impact on crowd behavior (this concerns the behavior of single members, social groups and the crowd as a whole). Helbing et al. (2000) assume “a mixture of socio-psychological and physical forces influencing the behavior in a crowd”. This includes aspects like walking speeds (Helbing et al. 2002), distances kept to other pedestrians or obstacles, “clogging” (Helbing et al. 2000, p. 488), “faster-is-slower effect” (Helbing et al. 2000, p. 489) or “herding” (Helbing et al. 2005, p. 20). Herding behavior occurs in situations with low visibility or insufficient orientation, e. g. in unfamiliar environment (Helbing et al. 2005, p. 21): “People either follow other people who are believed to know the best way, or they use the exit they are familiar with (typically the main exit they have entered).” This applies to buildings, but is definitely also true for flight behavior in the event’s surroundings, particularly when people have less knowledge of the place or view-shafts are limited. People will take their familiar routes and/or follow other people, especially in stressful situations, where orientation is all the more important. Because of herding effects, alternative escape routes are easily missed and therefore existing routes are not used effectively. Helbing et al. (2002, p. 23) pointed out that “pedestrians feel a strong aversion to taking detours or moving opposite to the desired walking direction, even if the direct way is crowded.” To reduce people’s uncertainty where to go and to guide them effectively on existing routes a well-elaborated urban design is needed.

Unlike visitors of most major events, who are relatively unfamiliar with the venue, e. g. soccer fans are characterized by high familiarity with the stadium and its surroundings and use the same paths many weeks a year. Extensive knowledge of the event’s venue has an impact on the visitors’ compliance with security service instructions. If some roads are blocked, it will be quite hard to prevent visitors from using their habitual routes. In many cases it will implicate uncertainty or resistance and therefore time delay for overall evacuation. Perilous situations can always arise, if single persons feel confident to find the “best way” completely on their own. This also became apparent in Love Parade 2010 immediately before the disaster occurred, when single persons started to use narrow stairs to escape and many people tried to follow.

If, e. g. a soccer stadium has to be evacuated for some reason, it is assumed that not tens of thousands of visitors are expected to flee from the building at once. As far as possible, only several sections of the building will be evacuated, not the whole stadium at once. Apart from that, it is known from evacuation of burning buildings, that people do not start leaving the building immediately. A “pre-movement time” delays evacuation for a few seconds to several minutes, in which people try to find out what is happening and to warn and gather family and friends (Proulx 2003, p. 34). The essential factor for reducing evacuation time is to optimize the time in which visitors start moving. “Design parameters such as exit width and travel distance, which have been equated traditionally with predicted escape times, are less likely to be related to overall evacuation times than is the time for people to start to move to safety” (Proulx/Sime 1991, p. 844). Definite information and concrete behavior instructions are important to implicate prompt reaction as well as to make sure that people are guided effectively and safely. Existing routes – in and outside the building – have to be able to manage the stream of people pouring out of different building exits.

Contrary to general opinion, there is little ruthless and egoistic behavior during and immediately after disasters, “panic is actually rare” (Drury/Cocking 2007, p. 9), but mutual assistance is at the very fore (see also Quarantelli 2003, p. 4). Socio-psychological research about fear and panic behavior in flight situation shows that groups of people, especially families and friends with strong ties, stay together if possible (Mawson 2005). This is even, or rather especially, in cases of emergency (Mawson 2005). In fact, making contact with affiliated persons takes precedence over individual flight (Sime, 1983). The loss of companions and uncertainty about their well-being has a destabilizing effect for people affected by disaster, whereas the presence of companions is reducing fear (Mawson 2005).

The presence of groups has great impact on crowd behavior in case of evacuation. As mentioned before, the presence of groups delays the starting point of evacuation. Mawson (2005, p. 107) emphasizes that “people in groups of familiars [...] wait to assemble with their primary group before evacuating.” Because of their “primacy of attachments” (Mawson 2005, p. 107), families and friends try to stay together, and if this fails, they are expected to stop or even turn back to search for lost companions. This again will hinder the stream of fleeing people and will complicate access of emergency services to the venue in the case of a large-scale

accident. That fact strengthens the need for an adequate guidance system outside the building. The following table shows the most influencing human factors and their consequences for the pedestrian flow (table 2).

Human factors	Consequences for pedestrian flow
Social groups (members stay together or search for each other)	Time delay and physical obstacles
Herding and familiar routes	Existing route grid is not used effectively + Difficulties in directing people on alternative routes
Environmental perception and orientation	Basic requirement to guide people and to give instruction
Mutual assistance	Evacuation is relatively ordered, panic is rare

Table 2: Human factors and their consequences for the pedestrian flow.

4 CASE STUDY SOCCER STADIUM

The research project REPKA deals with open space evacuation of the soccer stadium in Kaiserslautern/Germany. Here, a large scaled crowd with up to 50.000 soccer fans leaves almost every second week the stadium and the area around. Especially such events are vulnerable to many potential and realistic dangers: fan riots, attacks, large scaled accidents.

The soccer stadium is located in the inner city of Kaiserslautern. It is situated 40 meters above other parts of the inner city and lies in the middle of a residential area (Fig. 1). The consequences are clear – a difficult topography with steep slopes and a close link to the residential neighborhood complicate an ordered and fast evacuation. Making things not easier, the escape routes mostly are access routes for rescue teams at the same time. Here, a high risk and conflict potential is obvious. Due to land-use type, topography, basic traffic grid and a moving mass of people, the installation of completely free access routes is very complicated. Depending on the scenario, the declared safety areas are far away from the stadium, because of the high building density in the stadium’s surroundings. Declared safety areas need an open ground to serve as assembly points for injured people and to set up emergency equipment.

Consequently, it is not enough only to let the crowd leave the building in good order. The crowd has to be brought further away to safety. As figured out from the presented influencing factors on flight behavior, the crowd itself and the event’s surroundings play a decisive role. As shown in chapter 3.2 it is relevant to reduce the time in which people start to move, but here the focus of the research is on the situation after the crowd has already left the building.



Fig. 1: View on the Fritz Walter Soccer Stadium in Kaiserslautern from the South (source: REPKA project).

4.1 Methods

4.1.1 Urban spatial inventory-taking and analysis

The usage of escape routes is due to the interdependency of the individual perception and the behavior of the crowd around (herding etc.). The factual perception is also guided by environmental factors. Thus, in a first step there is the need to take a closer look at the research area with the help of a spatial inventory-taking and analysis. The general traffic routing is the basic grid for escape routes outside a building. Internally it consists of streets, sidewalks and footpaths distant to the streets. These three categories have their own characteristics, which are important to be suited as good escape routes for a fast evacuation. Especially the width is linked to a fast flow of persons away from disaster. Further influencing values are soil conditions, barrier-free design, existing view-shafts, signage and routes which have to be free for rescue teams. Here, research in law literature concerning evacuation of buildings can help to identify first benchmarks for outdoor regulations. The transport connection to safe areas and the means of transport available are also important. In a next step a spatial analysis follows, where neuralgic points and routes hindering a fast evacuation are identified. Serious deficits in the field of urban planning and design are revealed, which can be improved to assure an unhindered pedestrian flow. From the results of urban spatial and socio-psychological analysis, optimized escape routes are determined.

4.1.2 Socio-psychological analysis

At the Fritz Walter Soccer Stadium in Kaiserslautern 328 interviews with visitors were conducted in the run-up to two home matches of the local soccer club '1st FC Kaiserslautern' (1. FCK) in spring 2010. The interviews were carried out in short face to face interviews (5 to 10 minutes) using standardized questionnaires. The interviews deal with the visitors' perception of escape routes, their knowledge of the stadium and its surroundings, their information seeking behavior and preferred contact persons in case of emergency. Also included are aspects concerning shared arrival, like group size and companions attending the event. Interview participation was voluntary and analysis was anonymized. Most visitors showed great interest in taking part.

In addition, further findings on human behavior in emergency and flight situation were explored by literature research and studies about previous disasters. This expert knowledge is applied to an evacuation scenario of the soccer stadium in Kaiserslautern with regard to the local urban design characteristics. Evaluation occurs according to own experience (several observations of visitors going home after the end of the match) and the experience of the involved local security services.

4.2 Results

4.2.1 Urban design of the event's surroundings

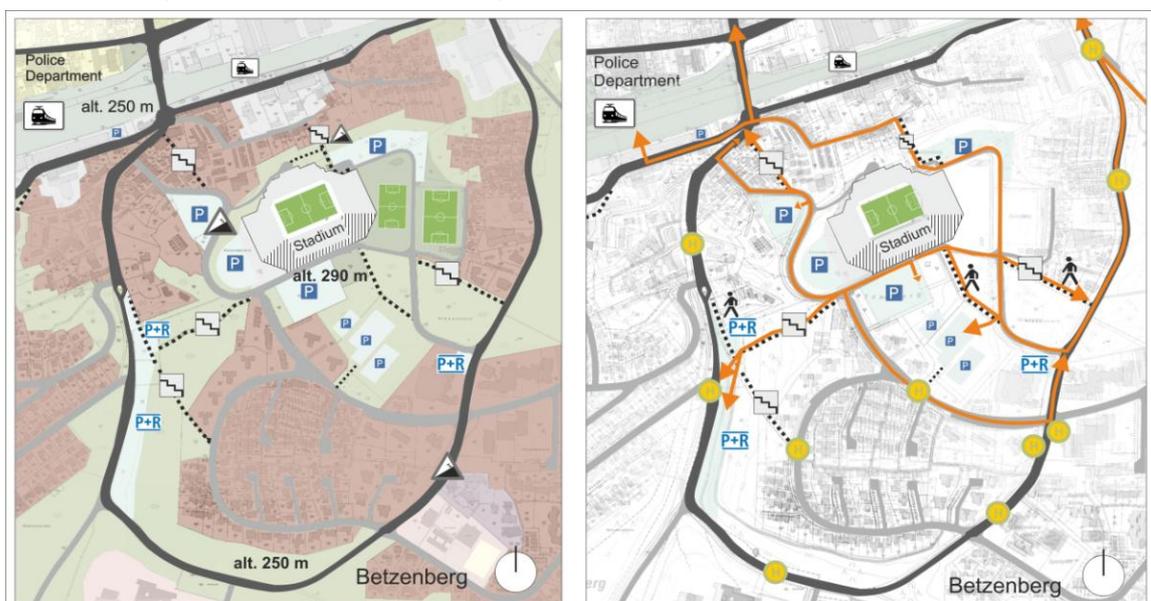


Fig. 2 and 3: Urban spatial inventory-taking and analysis (map not scaled) (own source).

Main contents of the urban spatial inventory-taking (Fig. 2) are the basic traffic grid, the parking, the topography and the surrounding land-use type. The traffic grid is extremely branched, because the stadium is intimately connected with the residential neighborhood. There are no linear routes leading away from the stadium, so the existing view-shafts are limited. The different path widths, especially in the intersection from streets to footpaths, cause “bottleneck effects” (Helbing et al. 2000). Potential destination for a part of the crowd is the parking, which is widespread all around the research area. “Park & Ride” stops are also far away from the stadium (defined as pedestrian flow source), which gives the crowd a chance to disperse. That could help to prevent congestion or “clogging”.

The spatial analysis (Fig.3) is geared to the situation after a soccer match and concerns itself with the terminating traffic of the pedestrians. The main destinations are the main train station, the city center in the North, the “Park & Ride” stops and also the parking in the stadium’s surroundings. The pedestrians encounter many different path widths with different soil conditions. Especially in the context of stairs, there are more than a few bottlenecks. In a next step, the results of the urban spatial inventory-taking and analysis can be compared with findings in the human factor analysis.

4.2.2 Characteristics and behavior of the crowd

The study of crowd characteristics at the Fritz Walter Soccer Stadium reveals that most attendees of the soccer match visit the event in small groups of two to four people (63 %) or even large groups of five and more people (26 %). More than half of the interviewed visitors are accompanied by friends (58 %) and many interviewees said that they visit the soccer match in company of their partner (25 %) or other relatives (24 %).

Visitors, who attend the soccer match in company of others, predominantly travel to the venue in this group constellation (77 %). Even larger groups of five and more people travel to the stadium together (53 %; small groups: 84 %). Many visitors (48 %) solely use the car to get to the stadium, 34 % use train or bus and 10 % use a combination of car and park and ride bus. Three persons use one car on average. The quantity of people using the respective means of transport modifies the destinations for parts of the pedestrian flow. This may increase bottleneck effects at narrow places. Summing up, soccer fans rarely visit the event alone, but in small or larger groups. These groups will try to stay together if somehow possible as ties are strong and they are reliant on each other, e. g. for going home by car.

Visitors are highly familiar with the stadium and its surroundings for the most part (79 % do not need any maps or signs to get to the venue and 68 % characterize their knowledge of the place as “excellent” or “good”). Because of their high familiarity with the venue, it will be difficult for security staff to send them on alternative routes. Thus, definite instructions from the guidance staff and sophisticated urban design are all the more relevant.

The study shows that members of the event’s security team obviously are the preferred contact persons if attendees have to ask for help. Present on location, clearly visible and accessible at any time (which is the case at soccer stadium), they are favored contact persons for visitors searching for help because of injuries (56 % would ask a member of event’s security team for help when their companion got injured; instead of asking other visitors (16 %) or calling for help via mobile phone (26 %)). This is confirmed by Coellen (1992, p. 105), who showed that people in extreme situations look for somebody to get a better orientation. This could be a person nearby who takes over leadership of the group in the first moment. Normally, this would be an official person.

In addition, the study shows that in information seeking behavior there is clear preference in use of personal information. Being asked about an actual situation in which they have to seek shelter from their actual position, most visitors (72 %) in our study definitely prefer personal information (that means information about what to do or where to go communicated by other people) to signpost (23 %) or technical support (3 %).

Awareness of risk and potential danger is obviously increased: Many visitors (44 %) said that they pay attention to emergency exits and escape routes intentionally when they are visiting major events. The older the people the more they do so (17 to 25 year olds: 27 %; 46 years and older: 63 %). Almost as many of them (41 %) said that they stay near emergency exits as possible.

4.3 Combining analysis

After getting some insights in the urban spatial characteristics on-site and the specification of the relevant human factors, the merging of both is the next logical step. The most interesting results are identified neuralgic points and routes, where clogging effects and congestion arise (Fig.4).

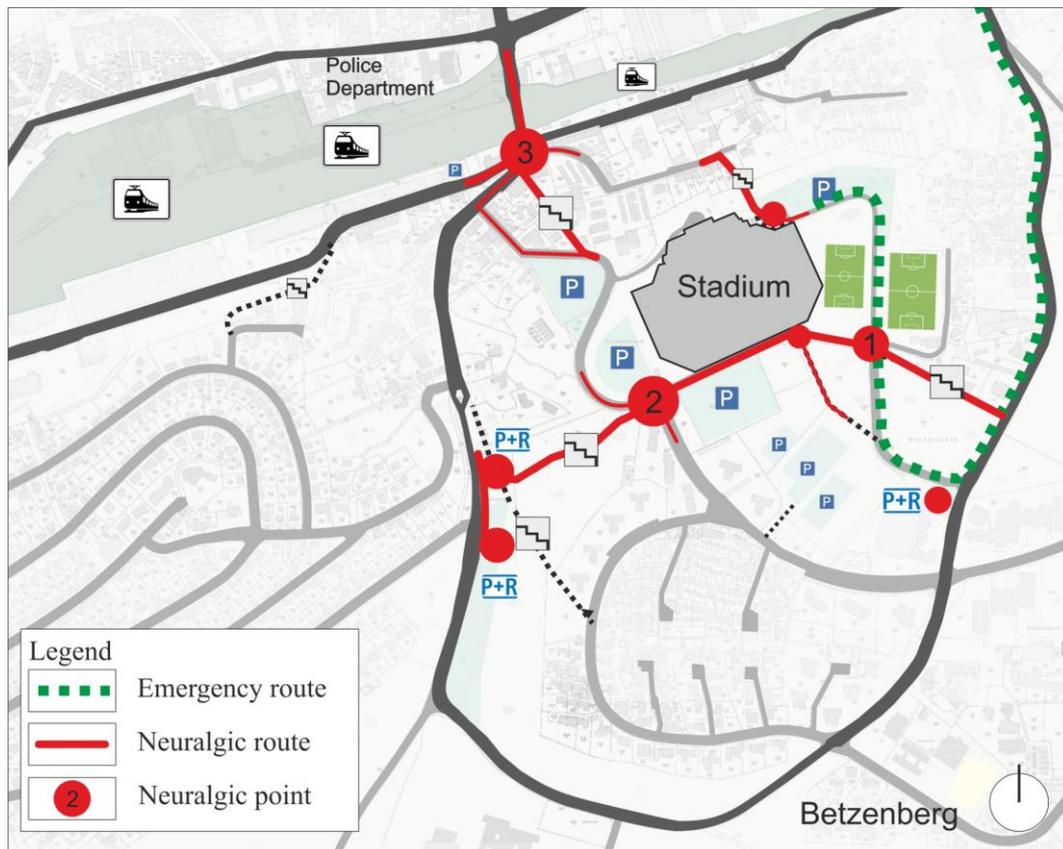


Fig. 4: Neuralgic points and routes (map not scaled) (own source).

These effects actually occur after every regular soccer match. In case of disaster, it is assumed that the effects will have much more fatal consequences. The reason is the lack of a good urban design in consideration of a large crowd moving to appointed destinations. But not only urban design plays a decisive role at these neuralgic points and routes. Also the crowd with its behavior and environmental perception, its composition of different group sizes and partly its unerring knowledge of the place is strengthening congestion and clogging effects.

A special case is the traffic routing of the emergency route, which should ensure fast access and departure of emergency vehicles. This route is crossed by a main pedestrian route in an eastward direction (neuralgic point 1). In order to keep the emergency route free of pedestrians, they have to be directed to the West. This causes more congestion at neuralgic point 2. Here is the most critical bottleneck (also at regular soccer matches) in the intersection from street to footpath. More than that, the footpath, at first slightly descending, gives way to long and steep stairs down to the Park & Ride stop. As consequence, the congestion spreads far into the adjoining streets. From the hitherto results of the influencing factors, an exemplary optimization is done (Fig. 5). With the help of guidance staff and signage the pedestrians find their optimal way to their destination. The guidance staff helps to organize an ordered pedestrian flow. More staff has to be positioned in the adjoining streets to split up the crowd. This aims for a more effective dispersion of the pedestrian stream. Furthermore, the existing foot path and following stairs can be widened without difficulty so that a higher quantity of people can take this path (green band). Consequently, the adjoining streets can be pressure reduced and balanced. Other aspects to be regarded are the visibility conditions in the evening after end of the match. Special lighting, like a traffic light system, can also be very helpful in guiding people safely away from disaster.



Fig. 5: Exemplary optimization of neuralgic point 2 (own source)

Also important is the situation at neuralgic point 3, where three different pedestrian streams come together at one choking point. In this area, where originally a traffic roundabout is situated, the streams are crossing each other, because the people are going to their main destinations: the train station and the city center.

5 INTERDISCIPLINARY APPROACH FOR OPTIMIZATION OF ESCAPE ROUTES

Essential factors influencing the crowd behavior in flight situations are identified and described in their consequences on pedestrian flow. It became clear that urban design aspects and human factors highly depend on each other. It is not sufficient to consider only one of them for a good planning of escape routes and improving evacuation. Figure 6 illustrates the combination of all identified aspects for a new approach for pedestrian evacuation planning.

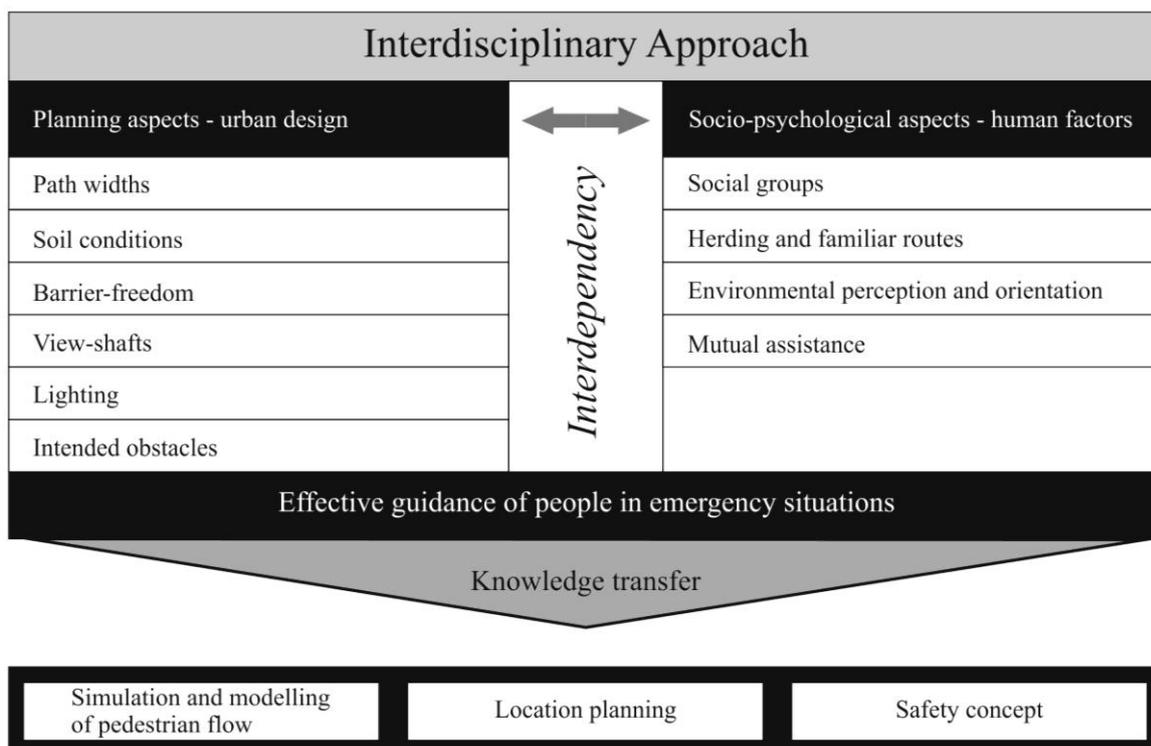


Fig. 6: Combining planning and socio-psychological aspects for interdisciplinary approach.

The combination of urban design aspects and human factors results in a definitely more effective guidance of people in emergency situations (as exemplary illustrated in figure 5). These findings can be transferred to research on modeling of pedestrian flows in computer evacuation simulation. Regarding human factors in simulation models, simulation of pedestrian flow becomes more realistic (Köster et al., 2011) and helps to identify neuralgic points, which can be optimized by urban planning intervention. Location planning of major events, including planning or modification of parking, access routes, positioning of security staff, etc. up to the elaboration of the event's safety concept, also benefits from this interdisciplinary approach.

Further research should consider more detailed the behavior of crowd and groups encountering obstacles and behavior in stress situations. Conditions of a spatially wide ranged evacuation should be regarded in events' safety concepts to more extent.

It became evident that the planning of escape routes and the effective use of these routes need a wide and holistic consideration – regarding human perception and behavior. Humans are in the focus of urban planning and design, so new approaches, including aspects of social psychology, are needed. This makes a contribution to a new holistic approach in the field of pedestrian evacuation planning.

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