A Scoping Review for the Parameters of Crowd Movement

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A Scoping Review for the Parameters of Crowd Movement

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En omfattande litteraturstudie av de parametrar som påverkar förflyttning i en folksamling

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Abstract
Existing models which describe crowd movement are running out of time and are failing to take the change of people's characteristics into account. The purpose of this study is to determine the "state-of-the-art" regarding the research within the field of crowd movement and identify parameters that influence crowd movement. To do this, a scoping review was conducted and the articles that were found were analyzed further according to a systematic framework. The outcome of the scoping review was an in-depth analysis of thirty-five articles. This analysis resulted in fifty identified parameters and the analysis of relationships between those showed that twenty-two of them may be considered as fundamental. Suggestions of further research are presented with respect to the articles included and the analysis made. This future research may be focused on the twenty-two fundamental parameters and in particular six out of those twenty-two.

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Summary

Existing evacuation models incorporate parameters like occupant flow rates and walking speeds. The underlying data for those parameters were collected in the middle of the 20th century and its reliability has been questioned. The main issue in this regard is that the existing models for evacuation, fails to take demographic changes or personal characteristics into consideration. Those changes may result in different behaviors during crowd movement and there might be a need for change in the built environment to make sure that a satisfactory egress process is possible. To be able to model and predict crowd movement, this kind of demographics or personal characteristics must be taken into consideration. The approach in which crowd movement are modelled by averaging parameters like occupant flow rate and walking speed may be to coarse. A more detailed approach may be preferable in which the more detailed parameters that categorizes the movement of each individual within a crowd are considered. So instead of describing crowd movement with coarse parameters like occupant flow rate or walking speed, more detailed or fundamental parameters should be identified and implemented in future models of crowd movement.

In order to achieve the objective of this study, a scoping review was conducted. The articles that were identified during the scoping review were analyzed and a total of fifty parameters were identified. The relationships between these parameters were then identified, which showed that twenty-two out of the fifty parameters may be considered as fundamental parameters according to the analysis. Even though those twenty-two parameters are considered as fundamental, the other identified parameters are not shown to be negligible. The twenty-two parameters that are considered to be fundamental are:

- Age	- Emotional state	- Health status	- Step frequency
- Body projection area	- Fatigue	- Height	- Step size
- Bottlenecks, openings	- Fitness	- Lateral sway	- Vision
- Culture	- Gender	- Personal space	- Weight
- Occupant density	- Group size	- Social relations	
- Emergency or non-emergency	- Headway	- Stair gradient	

A mapping of the research field with respect to the identified parameters, type of study and equipment has been made and the uncertainty associated with the methodology used has been discussed. Also, suggestions of future research have been proposed based on the content of the articles and the result of the analysis.

Sammanfattning

De existerande utrymningsmodellerna baseras på parametrar som personflöde och gånghastighet. Den data som dessa parametrar grundas på inhämtades under mitten av 1900-talet och dess tillförlitlighet har ifrågasatts. Tvivlet kring tillförlitligheten handlar framförallt om att de existerande modellerna misslyckas med att ta olika personegenskaper eller demografiska skillnader i beaktning. Då olika personegenskaper så väl som demografiska skillnader kan resultera i att olika beteenden vid förflyttning i en folkmassa, kan nya utföranden på den byggda miljön komma att vara nödvändiga för att kunna uppfylla en tillfredställande utrymning. Alltså måste varierande personegenskaper och demografiska skillnader inarbetas i de modeller som används för att modellera förflyttning i folksamlingar. Det tillvägagångssätt där personflöde och gånghastighet används kan vara för grovt och ett mer detaljerat tillvägagångssätt, där skillnader i personegenskaper och demografiska skillnader beaktas, kan vara att föredra. Så istället för att beskriva folksamlingars förflyttning med grova parametrar som personflöde och gånghastighet, kan mer detaljerad information användas. Sådan detaljerad information kan vara parametrar som visat sig påverka hur förflyttning i en folksamling sker.

För att kunna identifiera denna typ av parametrar har en ”scoping review” genomförts. De artiklar som identifierats i denna studie analyserades mer ingående. Totalt femtio parametrar identifierades och analyserades med avseende på samband sinsemellan. Sambandsanalysen resulterade i tjugotvå parametrar vilka anses vara av fundamental karaktär när förflyttning i en folkmassa ska beskrivas.

Det bör noteras att även ifall dessa tjugotvå parametrar anses vara av fundamental karaktär kan de andra identifierade parametrarna inte uteslutas eller antas vara försumbara. De tjugotvå parametrar som identifierats som fundamentala är:

- Ålder	- Emotionellt tillstånd	- Hälsostatus	- Stegfrekvens
- Kroppsprojektionsyta	- Utmattning	- Längd	- Steglängd
- Flaskhalsar, öppningar	- ”Fitness”	- Kroppsgungning	- Synfält
- Kultur	- Kön	- Personligt utrymme	- Vikt
- Persondensitet	- Gruppstorlek	- Sociala relationer	
- Nödsituation eller inte	- ”Headway”	- Trapplutning	

En kartläggning av forskningsfältet med hänsyn till de identifierade parametrarna, typ av studie och den utrustning som använts vid experiment utfördes för att ge en överblick av den forskning som redan genomförts. Osäkerhet kring den använda metoden diskuteras och förslag på framtida forskning presenteras baserat på den information som hittats i artiklarna samt på de resultat som erhållits från analyserna.

Acknowledgements

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1 Introduction

Existing evacuation models incorporate parameters like occupant flow rates and walking speeds. The underlying data for those parameters were collected in the middle of the 20th century and its reliability has been questioned. Thompson, Nilsson, Boyce, and McGrath (2015) highlights this problem and describes that some recent research indicates that increasing obesity rates and an increase of elderly people are to be expected in the future.

The main issue in this regard is that the existing models for evacuation, fails to take the changes of people characteristics into account. The demographic changes that are to be expected in the future, i.e. increased obesity rates and increased amount of elderly people, has been shown to have an direct impact on the occupant flow rates and walking speeds (Thompson et al., 2015). Those changes may result in different behaviors during crowd movement and there might be a need for change in the built environment to make sure that a satisfactory egress process is possible.

Almejmaj, Meacham, and Skorinko (2014) highlights the difference in demographics and claim that the demographics has a direct impact on the walking speed within a crowd. There is an indication that the movement within a crowd differs depending on what part of the world that are studied, the religion that is present there and other parameters that may be related to the demographic differences.

To be able to model and predict crowd movement, this kind of demographics or personal characteristics must be taken into consideration. That the existing models should be able to describe all kind of crowds are not a reasonable assumption and a development regarding the models for crowd movement is necessary. The approach in which crowd movement are modelled by averaging parameters like occupant flow rate and walking speed may be to coarse (Thompson et al., 2015). A more detailed approach may be preferable in which the more detailed parameters that categorizes the movement of each individual within a crowd are considered.

It’s possible that some studies have investigated the parameters that impact the crowd movement, i.e. the movement of a group of people which depends on the characteristics of each individual and interactions between the individuals. If so, this research would be of great importance to the development of crowd modeling. However, for the best knowledge of the author of this thesis, no earlier attempts have been made to describe crowd movement with the parameters of each individual and the interactions between the individuals. So instead of describing crowd movement with coarse parameters like occupant flow rate or walking speed, more detailed or fundamental parameters should be identified and implemented in future models of crowd movement.

There is, in other word, a need for development in the field of crowd movement. Both with respect to update the reference data sets but also to identify the specific parameters that have an impact on these models. This would enable the possibility to use the same flexible, mathematical model independent of which population or part of the world the model is to be used.

1.1 Objective

The main objective is to determine the state-of-the-art of research in the field of crowd movement, more specially, to determine the gaps and opportunities in the current analytical approaches. This means that disciplines like fire evacuation, pedestrian movement, biomechanics and computer modelling must be explored.

1.2 Methodology

The process behind this thesis is presented in Figure 1 below. In the first phase, which were the scoping review, the aim was to identify as much of the existing research, within the current topic, as possible. A scoping review is a systematic and comprehensive way to search the literature and is especially useful when looking across disciplines, which the literature review in this thesis required. Also, during the mapping of the literature, a scoping review was a very useful tool. When the scoping review was done, the outcomes were summarized and analyzed. The most important findings and suggestions of future research were then provided.

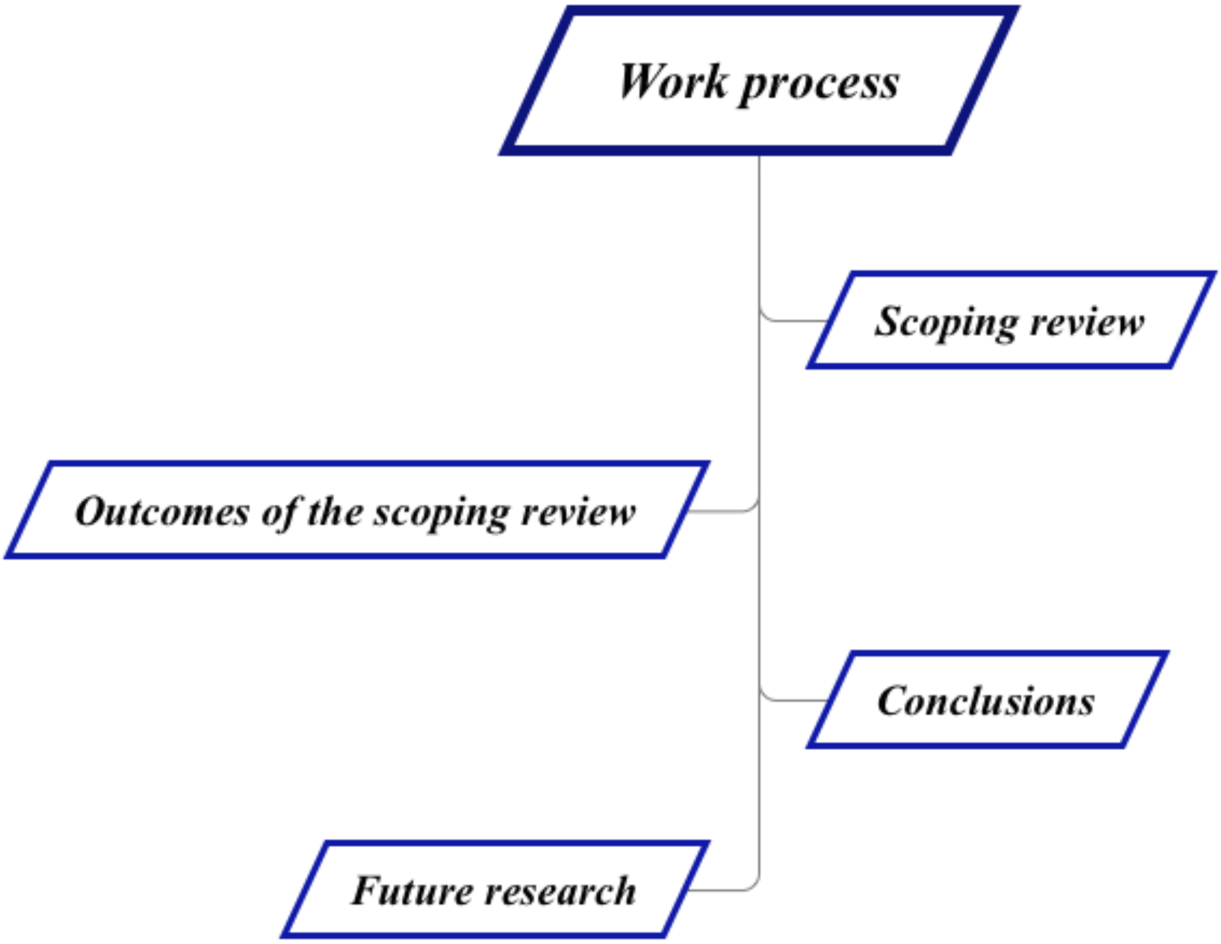

Figure 1 - Flow chart

1.3 Scope

In this thesis, the focus has been on human parameters that influence the movement within a crowd. Environmental aspects have only been considered if the interaction between a person and the environmental object were described. Also, the study has been limited to crowd movement on horizontal surfaces and stairs.

In general, only people standing on their feet have been studied, i.e. crawling or similar responses to environmental conditions have not been considered. For practical reasons the literature used were limited to the English language.

2 The scoping review

As a framework regarding the performance of a scoping review, the methodology by Arksey and O'Malley (2005) was used. Arksey & O'Malley stress that an explicit approach is of great importance and that the whole methodology shall be documented carefully to make sure the study may be replicated by others. The suggested process of a scoping study is as follows:

1. Identifying the research question
2. Identifying relevant studies
3. Study selection
4. Charting the data
5. Collecting, summarizing and reporting the results

The procedure used within this thesis, according to the topics above, will be further described in the following sections.

2.1 Identifying the research question

In this initial stage of the scoping review the research question was determined. Arksey & O'Malley recommend using a wide approach to be sure to get a comprehensive coverage of the research field (Arksey & O'Malley, 2005). The research question used for this thesis was:

"What parameters have an impact on unidirectional crowd movement?"

The research question aimed to identify parameters on the individual level that contributes to the crowd movement as a whole.

2.2 Identifying relevant studies

This phase of the scoping review aims to identify as many articles as possible that answer the research question. To do this, a list of keywords were developed. Those keywords were then formed into four combinations which aimed for different aspects of research within the field of crowd movement. The list of keywords and the search strategies may be found in Appendix I – Keywords and combinations. Those four combinations were formulated in a way to maximize the width of the search within the databases. The aim of each search combination is presented in Table 1 below.

Table 1 - Aim of each search combination

Search	Aim
1	Modelling/simulation research about crowd movement
2	Experimental research about crowd movement and the interaction between different individuals
3	A combination of Search 1 and Search 2, the purpose of this search was to get a wider approach and collect any studies which may have been missed in the previous searches
4	Experimental research about crowd movement and the interaction between different individuals. Note, not the same interaction as in Search 2

A total of three databases were used during the search, more specifically LUBsearch, Scopus and PubMed. The result of the searches was 5782 articles of which 4908 could be exported to EndNote and analyzed in more detail.

2.3 Study selection

In this phase, an exclusion process of the identified articles from the previous stage were conducted. An initial approach to do this was to delete all the duplicates, which were 1767. The deleted articles may be found in the Appendix II - EndNote, which is a digital copy the EndNote library. Then a set of exclusion/inclusion criteria were formulated, those criteria are presented in Table 2 below.

Table 2 - Exclusion and inclusion criteria

Inclusion criteria	Exclusion criteria
• Articles that focus on the physical aspects of human movement in unidirectional crowd movement will be included • Experimental, modelling/simulation, reviews and discursive/commentary articles will be included • Modelling/simulation studies have to be based on real human data, or when an artificial situation is set up and the subjects are filmed without their knowledge, or laboratory based human data.	• Articles dealing with bidirectional or/and counter flow will be excluded • Pure animal studies will be excluded • Articles that do not mention human anatomical or biomechanical movement parameters will be excluded • In vitro studies will be excluded • Articles not in English will be excluded

The actual exclusion process consisted of a couple of steps. In the first step, all the titles were read and compared to the exclusion/inclusion criteria. Those titles that were uncertain if they meet the inclusion criteria were saved for closer review. During the “exclusion by title”-phase a total of 1466 articles were excluded. The excluded articles may be found in Appendix II - EndNote.

In the second step of the exclusion process, the abstracts of the remaining papers were compared to the exclusion/inclusion criteria. Again, if there was any uncertainty if an article should be included or excluded it was saved for closer review. During this phase, called “exclusion by abstract”, a total of 1151 articles were excluded. As for the duplicates and the articles that were excluded by title, the articles excluded by abstract may be found in Appendix II - EndNote. There were 30 articles that weren’t possible to access the abstract during this phase, those articles may be found in the Appendix II - EndNote as well.

Along with the process of reading all the abstracts, ratings of 1 to 3 were made. Rating 1 was a score for the most relevant and was read first and Rating 3 is the least relevant. The purpose of this rating was to make the final number of articles manageable for the author of this thesis. Hence, only the articles of Rating 1 have been read in full. The criteria used for the rating is presented in Table 3 below.

Table 3 - Criteria for the rating of articles

Rating	Criteria
1	Meets the inclusion criteria and is directly and highly relevant to the scoping review question i.e. the article's main focus examines actual physical human crowd movement
2	Meets the inclusion criteria and is moderately relevant to the scoping review question i.e. the topic is still crowd movement, but the main focus is not necessarily actual physical human movement within a crowd, but rather other aspects of crowd movement that has an impact on physical movement
3	Meets the inclusion criteria, does not fit into categories 1 and 2, and is minimally relevant to the scoping review question

The result of the rating process were; 75 articles in the rating 1 category, 290 articles in the rating 2 category and 143 in the rating 3 category. The articles in each category are found in Appendix II - EndNote.

The third step was to read and exclude articles based on the full text. Due to the number of articles and the limited time for the work of this theses, only the articles in the Rating 1 category were read in full. This exclusion process resulted in a total of 40 articles excluded, which leaves 35 articles which were taken into further analysis. To clarify, a total of 75 articles were categorized into the Rating 1 category. 9 of those articles did not fulfill the inclusion criteria and another 17 were not available to read in full. This left 14 articles uncategorized. Some of those 14 were duplicates and are included in the number of deleted duplicates. Also, some of those 14 were transferred to Rating 2 or Rating 3 due to the content and are included in the number presented for those categories. The excluded articles and the articles that weren't available may be found in Appendix II - EndNote.

As a final comment for this section a summary of the information that may be find in the Appendix II - EndNote are presented. All the 4908 articles collected are found in this appendix. They are categorized according to the phase in which they were excluded of rated. The removed duplicates may be found as one category. Excluded by title, excluded by abstract and excluded by full text may be found. The articles that weren't accessible are found and the articles in Rating 1, 2 and 3 may be found within Appendix II - EndNote as well.

2.4 Charting the data

When all the articles had been reviewed and the final number of articles were set, the data from the remaining 35 articles were ready to be extracted, see reference list. To do this, an excel sheet was created, and this data extraction sheet may be found as Appendix III – Data extraction sheet, which is a digital version of the excel sheet. The information from the 35 remaining articles may be found within this sheet. In the sheet, each row represents an article and each column a property of the article. The properties that are found in the data extraction sheet are presented and explained in Table 4 below.

Table 4 - Properties extracted from the articles

Property	Explanation
Author	The author(s) of the article
Year of publication	The year in which the article was published
Title	Title of the article
Journal/publisher	The journal in which the article is published or publisher of the article
Geographical location	The country in which the article was published
Horizontal/stairs	States if the study is about movement on horizontal surface, in stars or both
Type of study	States if the study is an observational study, a lab experiment or field experiment, modelling/simulation study or a review
Aim	The aim of the study
Instruments/equipment used	What instruments or other equipment that were used during the experiments, if it's an experimental study
Emergency/Non-emergency	Declares if the article deals with emergency movement or non-emergency movement
Sample size	How many people that participated in the study
Study cohort	What kind of participants was studied
Future direction	Suggestions for future research from the author(s)
Identified parameters	Characteristics of individuals, or interactions between individuals, which influence the movement within a crowd. As well as environmental conditions which influence the movement within a crowd
Main findings	Description of relations or main findings about the identified parameters

2.5 Collecting, summarizing and reporting the results

During this stage, the articles were going to be collected, the information summarized and presented in relation to the used framework. As the articles were collected during the earlier stages, the remaining work was to summarize the results and present them.

The key information may be found in Appendix III – Data extraction sheet. The parameters found to have an impact on crowd movement are presented in Figure 2. All parameters that were mentioned within the articles to influence the crowd movement were collected. Those parameters are then described and the relationships between the different parameters are discussed. The identified parameters are then presented in Table 5, in which they are related to the type of study and what kind of equipment that were used during the experiment.

3 Outcomes of the scoping review

In this section the identified parameters are presented, explained when needed and relationships are analyzed. An overview of the research field is presented and methodological uncertainty discussed.

3.1 Identified parameters

As stated before, the scoping review resulted in a total of thirty-five articles which are included in this analysis, those articles may be found in Appendix III – Data extraction sheet. During the review of those articles, fifty parameters were identified and those parameters are shown in Figure 2 on the next side.

In the following chapters in this rapport the terminology are as follows; identified parameters refer to the parameters found in the included articles. Fundamental parameters refer to governing parameters, i.e. parameters that are not influenced by other parameters. Important parameters refer to non-governing parameters, i.e. the parameters that influence other parameters.

In the following sections under the current topic, each of the identified parameters are presented and relationships are discussed. The relationships between the identified parameters are then summarized in Figure 3 which may be found in section 3.2 Relationships between the identified parameters". The parameters are presented in the order they appear in Figure 2, with the psycho-social parameters first followed by the environmental parameters, the biomechanical parameters and the physiological parameters.

In the following sections the concept of positive and negative relationships is going to be used. If a relationship is said to be positive it means that if one of the parameters increases the other parameter in the relationship increases as well. And the opposite, if a relationship is said to be negative does it means that if one parameter increases the other parameter in the relationship decreases. Also, in some cases the term negative or positive have been used separately. In those cases, negative means that the parameter has a negative impact on the crowd movement, i.e. slow down the movement. Positive means that the impact make the crowd movement faster.

3.1.1 Emotional state

The emotional state has been mentioned to influence the crowd movement by W. Ma, Yarlagadda, and Eng (2015) and Ronchi, Reneke, and Peacock (2016). Within those articles, the emotional state refers to the motivation to keep on walking. It's mentioned the emotional state is related to the walking speed and the personal space, unfortunately are this relationship not further discussed or explained.

3.1.2 Emergency or non-emergency conditions

Within the literature, a difference regarding the crowd movement is mentioned depending on the conditions, i.e. if there are emergency or non-emergency conditions. About a quarter of the articles dealt with emergency movement. This identified parameter has been mentioned by Martinez-Gil, Lozano, García-Fernández, and Fernández (2017) which just state that there is a difference between the conditions.

Muhdi, Davis, and Blackburn (2006) claim that the walking speed is related to the conditions and Ronchi et al. (2016) describes the same relation in which the walking speed tend to be higher during emergency conditions. Thompson et al. (2015) describes a relation between occupant density and walking speed and there is an indication that the conditions (emergency or non-emergency) influence this relationship. Zhao, Lu, Li, and Tian (2017) describes an increase of the walking speed during emergency conditions and that the minimum headway is

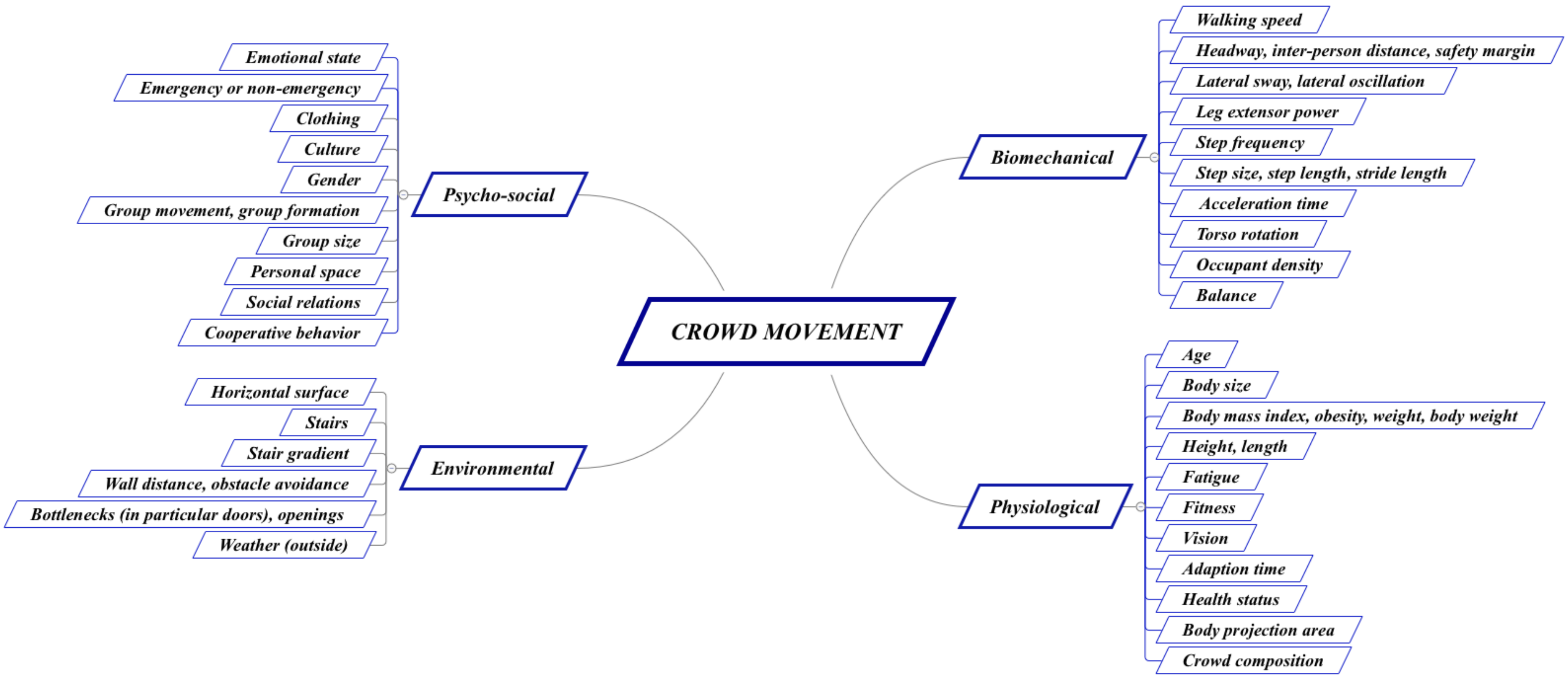

Figure 2 - The identified parameters that influence the crowd movement

shorter due to the decreased preference regarding the personal space. The identified parameter "headway" is presented in section 3.1.18. Also, Zhao et al. (2017) states that the relationship between walking speed and headway show the same trend regardless of the conditions, but that the magnitude differs. A relation between adaption time and the conditions is mentioned as well, in which the adaption time tend to be shorter during emergency conditions. The shorter adaptation time indicates that the preferred personal space is decreased during emergency conditions.

Lu, Chan, Wang, and Wang (2016) show that group movements are influenced by the conditions. In an emergency situation people tend to evacuate together and form patterns which allow communication during the evacuation.

3.1.3 Clothing

The clothes used may influence the crowd movement. Almejmaj et al. (2014) mentioned that earlier research had shown that the kind of shoe and kind of clothes that a person wears may impact the stride length and resulting walking speed. Ding, Chen, and Zhang (2016) did consider that clothing may influence the body projection area and Thompson et al. (2015) claim that clothes which enlarges the body of a pedestrian has a negative influence on the crowd movement. The relation between clothes and walking speed are mentioned by Muhdi et al. (2006) as well.

3.1.4 Culture

Depending on which part of the world a person lives and what cultures are present there, different acceptance regarding the personal space are observed (Almejmaj et al., 2014). The distance between persons in a crowd is related to the preferred personal space and what distance toward other persons feels comfortable. Bandini, Gorrini, Nishinari, and Pei-Luen (2016) describes the same relationship between cultural background and personal space, referring to lab experiments.

Fujiyama and Tyler (2010), Duives, Daamen, and Hoogendoorn (2015) and J. Ma, Song, Fang, Lo, and Liao (2010) claims that the walking speeds are different depending on the part of the world a person comes from and their culture as well, but mention that this relationship hasn't been quantified.

Shuchao et al. (2016) describes a relationship between headway and walking speed and that this relationship differs between cultures, this difference may be referred to the differences in body size and preferred personal space. The body size and preferred personal space may be the explanation to different walking speeds between different cultures as well (J. Ma et al., 2010).

Song, Lv, and Fang (2013) do argue for the dependence of cultural background on the acceleration time and the preferred distance to walls. Song et al. (2013) suggests that the difference in preferred distance to walls may be explained by differences in body size and preferred personal space. Since the body size differ between different cultures and how close people tend to be each other also differs with culture.

The relation between occupant density and walking speed are said to be influenced by cultural background as well by Martinez-Gil et al. (2017) and in the same article the impact of cultural background on group movement is mentioned. However, are those relationships not further discussed within the article.

3.1.5 Gender

Earlier research suggests that there is a difference between genders regarding the walking speed; males tend to walk faster than females (Fujiyama & Tyler, 2010). Juan, Lo, and Jian (2017) claim that this trend in which males walk faster than females applies to movement in stairs as well. Duives et al. (2015) highlights the difference in walking speed between the two genders and Koester and von Sivers (2015) claim that the personal space differs between genders. Unfortunately, neither of those articles provide any explanation why this difference is.

Y. Ma, Li, Zhang, and Chen (2017) mentions the difference in walking speeds and that males are more willing to overtake than females. Spearpoint and MacLennan (2012) claim that there is a relationship between gender and obesity, however this relationship is not quantified or further analyzed in the article. Zhang, Cao, Salden, & Ma, (2016) takes the gender distribution into consideration and there is an indication that this identified parameter do influende the crowd movement. However, is this influence not further analyzed within the article.

3.1.6 Group movement, group formation

Group movement refers to people who are walking within a group and group formation to the different patterns that are observed when people walk in groups. People which are familiar to each other tend to stay together during evacuation - mentioned by Bandini et al. (2016), Bode, Holl, Mehner, and Seyfried (2015), Ding et al. (2016), Lu et al. (2016) and Y. Ma et al. (2017). This behavior results in groups within a crowd becoming “moving obstacles” which influence the walking speed within the crowd in a negative manner.

Within the literature, the negative impact of group movement and group formation on the walking speed has been highlighted by Martinez-Gil et al. (2017), You, Gu, Fan, Zhang, and Hu (2016), Bandini et al. (2016) and Ding et al. (2016). It’s stated that the walking speed of a small group within a crowd in general are slower in comparison to a person walking alone within the crowd. This negative influence may be explained by the desire to stay together within the group and maintain a good communication. To maintain a good communication the need of different formations are required. The slower walking speed may also be a product of the dual tasking, i.e. walking and having a conversation in the same time which requires more cogitative resources and may result in a slower walking speed. Y. Ma et al. (2017) also describes that the persons within a group tend to have the same walking speed but that the walking speed may differ between groups. The group seem to adapt to the slowest walking person within the group. Almejmaj et al. (2014) describes that people who are walking in a group tend to walk slower in stairs than people who are walking alone.

3.1.7 Group size

A crowd often consists of several smaller groups and the group size refers to the number of persons within one of those smaller groups. A relationship between the group size and the walking speed is mentioned within the literature, in which an increasing group size results in a decreasing walking speed. This relationship is highlighted by Hoogendoorn et al. (2005), Gorrini, Bandini, and Vizzari (2015), Martinez-Gil et al. (2017) and You et al. (2016). Lu et al. (2016) describes the same relation between the walking speed and the group size, but stresses that this relationship isn’t proportional.

The group size may be related to the group formation which is highlighted by Gorrini et al. (2015) and You et al. (2016). The phenomena of “moving obstacles” is more likely to happen in groups consisting of more than two people (Y. Ma et al., 2017).

3.1.8 Personal space

The personal space is the area close to a person, much closer in comparison to the headway (see section 3.1.18) for example. Laboratory experiments indicates that the personal space is related to the walking speed (Bandini et al., 2016). Zhao et al. (2017) states that during crowd movement people tend to preserve their personal space if possible and W. Ma et al. (2015) claim that the personal space is related to occupant density. Von Sivers and Köster (2015) indicates that the personal space is a parameter that influences the movement within a crowd.

3.1.9 Social relations

In groups in which the members know each other, a cooperative behavior is likely to occur and in a group in which the members are unknown to each other it's likely that no cooperation occurs and the walking speed is reduced due to the phenomenon of "moving obstacles"

(Y. Ma et al., 2017). The occurrence of cooperative behavior due to social relations to the members of the group are highlighted by Martinez-Gil et al. (2017) as well. It has also been stated in the literature that the headway and personal space tend to be larger towards unfamiliar persons by Shuchao et al. (2016) and Song et al. (2013).

3.1.10 Cooperative behavior

When people cooperate during evacuation the evacuation time has been shown to decrease (Y. Ma et al., 2017). In the experiment conducted by Y. Ma et al. (2017), it was shown that in groups in which people knew each other they tend to help each other during evacuation. The exact relationship wasn't investigated but an indication to an increased walking speed was observed.

3.1.11 Horizontal surface

Depending on the surface on which the pedestrian is walking, different walking speeds are obtained. If horizontal surface represents the "normal case" regarding walking, it's shown that stairs and slopes gives a decreased walking speed in comparison to the "normal case". This dependence is highlighted by Fujiyama and Tyler (2010), Martinez-Gil et al. (2017) and Muhdi et al. (2006).

3.1.12 Stairs

Movement in stairs is shown to be slower than movement on horizontal surface. This relationship has been mentioned by Fujiyama and Tyler (2010), Juan et al. (2017), Fang, Song, Li, et al. (2012), Martinez-Gil et al. (2017) and Muhdi et al. (2006). Juan et al. (2017) does however claim that the walking speed in stairs are slower during ascending than descending movement.

3.1.13 Stair gradient

The stair gradient, i.e. the angle in which the stair is built, has been shown to influence the movement in stairs by Fujiyama and Tyler (2010) and Juan et al. (2017). A stair built within a greater angle tends to have a negative impact regarding the movement in stairs, i.e. the walking speed is decreasing when the angle increasing.

3.1.14 Wall distance, obstacle avoidance

The distance towards the surrounding walls or other obstacles are mentioned by Hua-Yan Shang (2017), J. Ma et al. (2010), Von Sivers and Köster (2015) and Zhao et al. (2017). The cause of this distance has not been explained within the literature.

3.1.15 Bottlenecks (in particular doors), openings

Bottlenecks and openings, in particular doors, are shown to have a negative impact on the occupant flow rate by Duives et al. (2015).

Martinez-Gil et al. (2017) claim that openings do influence the walking speed and Thompson et al. (2015) describes that the occupant flow is related to the walking speed. A fair conclusion with respect to the relations mentioned by Martinez-Gil et al. (2017) and Thompson et al. (2015) is that bottlenecks and openings do influence the walking speed in a negative manner, this conclusion should be further investigated and confirmed in future research.

3.1.16 Weather (outside)
Martinez-Gil et al. (2017) mentioning that the kind of weather may influence the walking speed and Duives et al. (2015) shows that for drizzle, rain and snow there is an increase regarding the walking speed.

3.1.17 Walking speed
Ding et al. (2016) and Kasperski (2017) states that the walking speed has an influence of the movement within a crowd. Ding et al. (2016) also describes that different persons within a crowd have different walking speeds. A slower-walking person tends to prevent people with a faster walking speed from maintaining their preferred walking speed, i.e. the slower-walking persons tend to become “moving obstacles”, which limit the average walking speed within the whole crowd if the occupant density is so high that overtaking is not possible.

A relationship between walking speed and the amplitude of lateral sway exists in which the amplitude increases as the walking speed decreases, this relation is mentioned by Juan et al. (2017) and Liu, Song, and Zhang (2009). Liu et al. (2009) mention a relationship between the walking speed and frequency of the lateral oscillation as well, in which a decreased walking speed results in a decreased frequency.

3.1.18 Headway, inter-person distance, safety margin
Headway and inter-person distance is the distance between a walking person and the person in front. Safety margin is the space preserved to avoid contact to the person in front during movement within a crowd and is a part of the headway parameter.

A linear relationship between headway and walking speed are described within the literature, a relationship in which a decreasing headway gives a decreasing walking speed. This relationship are highlighted by Juan et al. (2017), Duives et al. (2015), Lv, Fang, Wei, Song, and Liu (2013), Thompson et al. (2015), Martinez-Gil et al. (2017), Shuchao et al. (2016), Zhang, Cao, Salden, and Ma (2016) and Zhao et al. (2017). Juan et al. (2017) claim that this relationship is linear until a certain headway and when the headway exceeds this value there is no longer an influence on the walking speed due to the free walking speed already is obtained.

Zhao et al. (2017) claim that there is a critical value to the headway and an adaption is made regarding the walking speed to preserve personal space and avoid collision when this critical headway is achieved. This adaption in walking speed may be described by:

$$v = \begin{cases} 0, & L \leq d_{min} \\ k(L - d_{min}), & d_{min} < L < d_{min} + v_{max}/k \\ v_{max}, & L \geq d_{min} + v_{max}/k \end{cases}$$

In which v is the walking speed, L the headway, d_{min} critical headway, v_{max} the maximum unimpeded walking speed and k is a constant of proportionality.

Song et al. (2013) quantifies the linear relationship between headway x and walking speed y by:

$$y = 1{,}46x - 0{,}0432$$

A relationship between the headway and the occupant density is described by Shuchao et al. (2016) and Fang, Song, Liu, et al. (2012), who claim that a decreased headway results in an increased occupant density.

Both Fang, Song, Liu, et al. (2012) and Song et al. (2013) describe a positive relationship between headway and step length in which a decreased headway gives a decreased step length. They do also describe a positive, linear, relationship between headway and step frequency in which an increased headway gives an increased step frequency and quantifies this relationship with the following equation:

$$f_s \in \begin{cases} (0{,}714 + 1{,}385d - 0{,}2; 0{,}714 + 1{,}385d + 0{,}2) & (d < 0{,}9285) \\ (2 - 0{,}2; 2 + 0{,}2) & (d \geq 0{,}9285) \end{cases}$$

In which f_s is the step frequency and *d* the headway. Two Hz is the unimpeded step frequency and the numbers $\pm 0{,}2$ represent the standard deviation.

Mai, Song, and Ma (2015) claim that headway during single-file movement differs from the headway in a two-dimensional situation. It's stressed that this relation must be further investigated in two-dimensional situations.

3.1.19 Lateral sway, lateral oscillation

The lateral oscillation or the lateral sway refers to the body sway, i.e. how much the body is swinging in lateral direction during movement. Juan et al. (2017) describes that an increasing lateral sway results in more occupied space of a person and therefore a larger body projection area and Song et al. (2013) claim that an increasing lateral oscillation gives an increase regarding the occupant density. A relationship between headway, lateral oscillations and occupant density is presented by Shuchao et al. (2016), in which a decreasing headway results in an increase regarding the lateral oscillations and occupant density.

3.1.20 Leg extensor power

The leg extensor power has been shown to influence the walking speed in stairs by Fujiyama and Tyler (2010). It seems like the walking speed increases with an increasing leg extensor power, at least in stair movement.

3.1.21 Step frequency

The step frequency has a relation to the walking speed in which an increased step frequency results in an increased walking speed. This relation has been highlighted by Kasperski (2017), Fang, Song, Liu, et al. (2012), Song et al. (2013) and Stuvel, Magnenat-Thalmann, Thalmann, Stappen, and Egges (2017).

3.1.22 Step size, step length, stride length

Step size and step length refers to the length of a step and stride length are the length of a step cycle. The step length or stride length relationships to the walking speed are highlighted by Almejmaj et al. (2014), Kasperski (2017), Fang, Song, Liu, et al. (2012), Song et al. (2013) and Stuvel et al. (2017). Hua-Yan Shang (2017) stresses that different step lengths within a crowd have a positive impact on the crowd movement and Koester and von Sivers (2015) describes that the walking speed are adapted during crowd movement by an adaption in the stride length. Koester and von Sivers (2015) claim that there is a positive relationship between step length and walking speed in which an increased step length gives an increased walking speed.

3.1.23 Acceleration time

The acceleration time (called "relaxation time" in some of the literature) refers to the time it takes to accelerate into the desired or possible speed. This identified parameter is mentioned by Zhao et al. (2017) and J. Ma et al. (2010) but the influence on the crowd movement seems to need further investigation.

3.1.24 Torso rotation

The identified parameter "torso rotation" refers to the tendency observed in which a person turns their upper body for a short moment to pass an obstacle or another person. The torso rotation enables more people to pass the obstacle in the same time and is highlighted by Duives et al. (2015) and Stuvel et al. (2017). The torso rotation is mainly observed during movement through a door or opening, but even during movement within a crowd where bypassing slower pedestrians occurs. However, whether the torso rotation has a negative or positive impact on the crowd movement is not clear, so this identified parameter needs some further research.

3.1.25 Occupant density

A relationship between occupant density and walking speed is frequently mentioned in the literature, in which an increasing occupant density results in a decreased walking speed. This relationship has been mentioned by Juan et al. (2017), Duives et al. (2015), Fang, Song, Li, et al. (2012), Liu et al. (2009), W. Ma et al. (2015), Y. Ma et al. (2017), Martinez-Gil et al. (2017), Muhdi et al. (2006), Shuchao et al. (2016), Song et al. (2013), Thompson et al. (2015), Waldau et al. (2007) and Zhang et al. (2016). The same relationship is mentioned by Kasperski (2017) who claims that a denser crowd makes the slow-walking pedestrians become "moving obstacles" which force the fast-walking pedestrians to either reduce their walking speed or overtake. But the possibility to overtake within a dense crowd is rather limited or not possible.

The occupant density has been related to step size and step frequency in the literature as well, Fang, Song, Liu, et al. (2012) describes this relationship in which an increasing occupant density gives a decrease in both step length and step frequency. This relationship has been mentioned by Von Sivers and Köster (2015) as well, but the step length was replaced by stride length.

An increasing occupant density has in addition been shown to give an increase regarding the lateral oscillation, which has been highlighted by Liu et al. (2009) and Shuchao et al. (2016).

Waldau et al. (2007) describes that an overlap behavior was observed during some experiments, in which people tend to start marching in each other's steps by taking longer steps and placing them on the side of the person in front. This behavior does optimize the usage of the available space and allows a higher occupant density to be present.

3.1.26 Balance

Juan et al. (2017) describes that during movement in stairs a person must pay attention to maintain their balance and that this reduces the walking speed in stairs.

3.1.27 Age

As people grow older and in particular over the age of forty, the walking speeds tend to decrease (Spearpoint & MacLennan, 2012). Within the literature this tendency is explained by the reduced mobility often observed in elderly people and that the decreased mobility is due to a reduced perception of light and colors, reduced muscle mass, and slower coordination and reflexes (Bandini et al., 2016).

In the experiments done by Bandini et al. (2016) it's observed that elderly tend to have a lower walking speed in comparison to adults. Thompson et al. (2015) claim that the reduction of walking speed is due to the decreased stride length which follows by age, it should be noted that this result is obtained from treadmill tests.

An increase regarding the inter-person distance, personal space and headway are described by Bandini et al. (2016), Koester and von Sivers (2015) and Shuchao et al. (2016). Shuchao et al. (2016) claim that elderly people have an increased adaption time as well. It's also described by Ding et al. (2016) and Ronchi et al. (2016) that elderly people seem to experience fatigue faster than adults.

The age distribution within a crowd is shown to have an impact on the crowd movement by Zhang et al. (2016) and Thompson et al. (2015).

3.1.28 Body size
The body size refers to both the height and the body projection area of a person. Within the literature, a relationship between walking speed and body size is mentioned. This relationship is highlighted by (Muhdi et al. (2006), Shuchao et al. (2016) and Song et al. (2013). However, the relationship was not explained. Also the distance to walls and obstacles are said to be influenced by the body size (J. Ma et al., 2010), neither this relationship has been explained within the literature.

However, even though the relationship between body size and walking speed wasn't explained within the literature, the body size consists of the height and the body projection area. A positive relationship is found to exist between height and walking speed (see section 3.1.30) and a larger body projection area to have a negative relationship to walking speed (see section 3.1.36). Hence, no conclusions may be drawn.

3.1.29 Body mass index, obesity, weight, body weight
The body mass index (BMI) has been shown to be related to walking speed, where an increasing weight results in a decreasing walking speed which has been highlighted by Fujiyama and Tyler (2010), Spearpoint and MacLennan (2012) and Thompson et al. (2015).

A relationship between body weight and body projection area is presented by Spearpoint and MacLennan (2012) and Zhao et al. (2017), in which an increasing weight gives an increasing body projection area.

Spearpoint and MacLennan (2012) claim that the body weight is influencing the balance and that obesity is more common within higher age.

Zhao et al. (2017) claim that the acceleration time is influenced by the body weight and (Thompson et al., 2015) indicates that there seem to be an increase regarding the lateral oscillation as well if the weight increases. In Thompson et al. (2015) the occupant density is said to increase with increasing body weight.

3.1.30 Height, length
A relationship between the height of a person and the walking speed has been mentioned by Lv et al. (2013) and Mai et al. (2015), and Liu et al. (2009) claim that this is a positive relationship in which taller persons tend to keep a higher walking speed.

3.1.31 Fatigue
The literature describes that fatigue has a negative influence regarding the walking speed. This relationship has been mentioned by Ding et al. (2016), Fang, Song, Li, et al. (2012), Luo et al. (2016), Y. Ma et al. (2017), Ronchi et al. (2016) and Spearpoint and MacLennan (2012).

Ding et al. (2016) and Luo et al. (2016) does also state that the fatigue is more commonly encountered during movement in stairs but it should not be neglected during horizontal movement

That a person that experiences fatigue may reduce their walking speed or even stop completely, becoming an obstacle for other persons, are described by Ding et al. (2016) and Ronchi et al. (2016).

Ronchi et al. (2016) describes that when a person experience fatigue is dependent on the persons fitness and the walked distance, Spearpoint and MacLennan (2012) adds obesity and age to this explanation.

3.1.32 Fitness
The identified parameter "fitness" refers to how fit a person is, i.e. their athletic and aerobic capability. Fitness is described to be positively related to the walking speed by Fujiyama and

Tyler (2010) and Koester and von Sivers (2015). The inverse relationship between fitness and fatigue has been highlighted by Ding et al. (2016) and Ronchi et al. (2016). i.e. the higher the level of fitness of a person, the lower the incidence of fatigue.

3.1.33 Vision

Zhao et al. (2017) claim that vision is the main tool for information gathering and describes a relationship between headway and vision, this relation is mentioned by Duives et al. (2015) as well. A positive relationship between vision and walking speed are presented by Bandini et al. (2016), Juan et al. (2017) and Fang, Song, Li, et al. (2012). Spearpoint and MacLennan (2012) claim that vision is related to balance as well.

3.1.34 Adaption time

The term adaption time (safe response time) refers to the time that is required for a person to react and adjust the walking speed or completely stop with the purpose to avoid collision and preserve the personal space (Zhao et al., 2017). Shuchao et al. (2016) claim that an increasing age may extend the adaption time.

3.1.35 Health status

A relationship between health status and fatigue has been mentioned by Ding et al. (2016) and Ronchi et al. (2016) in which a bad health status increases the possibility for fatigue to occur.

3.1.36 Body projection area

The body projection area refers to the occupied space by a person, as a plan-view. Imagine that a lamp is put straight over a person's head, then the shadow on the ground would represent the body projection area.

A relationship between the body projection area and occupant density is highlighted by Ding et al. (2016), Shuchao et al. (2016), Waldau et al. (2007) and Zhang et al. (2016). Liu et al. (2009) describes that an increased need of space or a larger body projection area decreases the walking speed within a crowd. The acceleration time is influenced by the body projection area as well (Zhao et al., 2017).

3.1.37 Crowd composition

Crowd composition refers to wherever there is a homogeneous or heterogeneous crowd distribution. Shuchao et al. (2016) claim that the crowd dynamics are influenced by the composition of the crowd. Both Shuchao et al. (2016) and Thompson et al. (2015) suggest that the crowd composition influence the walking speed.

3.2 Relationships between the identified parameters

With respect to the relationships described in the previous section, Figure 3 was created. From this figure, it may be seen that almost all the identified parameters are related to the walking speed in some way which indicate that the walking speed is an important parameter when describing crowd movement. The green, solid, lines mean that there is a positive relationship between the parameters i.e. if one parameter increasing the other increase as well. The red, dashed, lines mean that there is a negative relationship, i.e. if one parameter increase the other decrease and the black, dotted, lines states that there is a relationship but if it's positive or negative are not sure.

The procedure for the analysis regarding the relationships are conducted according to the following description. Since the walking speed seem to be related to many of the other identified parameters the analysis is based on the walking speed. Then the relationships shown in Figure 3, are used to track down which parameters that has an impact on the walking speed. The parameters that are said to be fundamental are the parameters that are not further influenced by any other of the identified parameters. For example, the parameter "Age" are shown to be a fundamental parameter in the paragraphs below. This statement is based on the fact that the parameter "Age" is shown to influence the walking speed, but when the parameter "Age" is examined it shows that no other of the identified parameters influences the parameter "Age". Hence, age is suggested to be a fundamental parameter. Same procedure is used during the identification of the other fundamental parameters.

Walking speed has been shown to be positively related to vision, fitness, height, step size, step frequency and headway. The step size depends on the headway, occupant density and if there is emergency or non-emergency conditions. The step frequency may be related to the headway as well. However, the occupant density is influenced by body projection area, preferred personal space, headway, lateral sway and if there is emergency or non-emergency conditions. If the relations to the personal space are investigated it is shown that the personal space differs with respect to age, gender, culture, emotional state and social relations as well as the conditions (emergency or non-emergency). The weight of a person, headway and walking speed do influence the lateral sway. The headway is influenced by social relations, vision and if there is emergency or non-emergency conditions.

Occupant density, age, weight, fatigue, body projection area, stairs, bottlenecks or openings, group movement, group formation and group size are parameters that have been shown to influence the walking speed in a negative manner. Fatigue can be related to health status, fitness, weight. The walking speeds in stairs are reduced due to the stair gradient so his should be a parameter to consider. Torso rotation may occur during movement through bottlenecks or openings and the size of the group influence the group movement and group formation.

To summarize, with the parameter "walking speed" as the starting point and the analysis presented above. The fundamental parameters of crowd movement are suggested to be:

- Age
- Body projection area
- Bottlenecks, openings
- Culture
- Occupant density
- Emergency or non-emergency
- Emotional state
- Fatigue
- Fitness
- Gender
- Group size
- Headway
- Health status
- Height
- Lateral sway
- Personal space
- Social relations
- Stair gradient
- Step frequency
- Step size
- Vision
- Weight

Note that while these parameters have been considered fundamental to address the crowd movement, this does not mean that the other identified parameters are negligible.

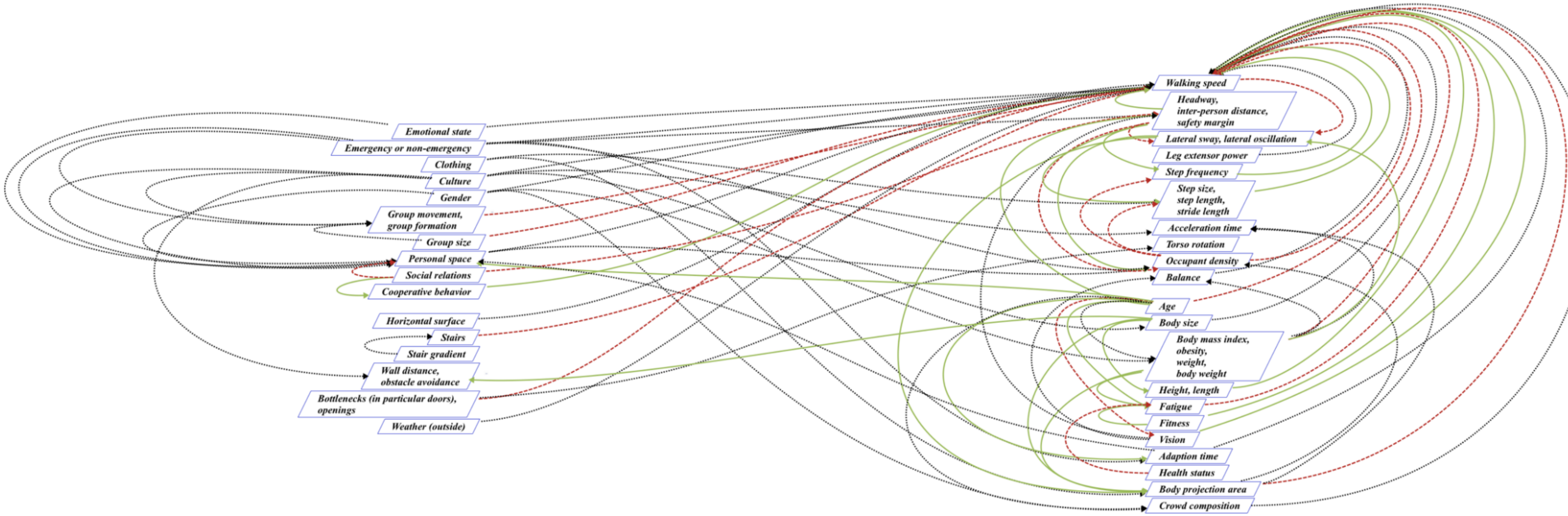

Figure 3 - Relationships between the identified parameters

3.3 Mapping the research field of crowd movement

To get an overview of the field and the research encountered during the scoping review the thirty-five included articles were summarized in Table 5. In this table, each identified parameter is represented by a row and the type of study by a column. The markers represent what kind of equipment that were used if any experiments were done in the article. If a parameter was found in an article that was a mixture of the different type of studies, a mark has been set on each type of study column that were affected.

For example, the parameter "age" has been mentioned within all the types of studies encountered. One time in an observational kind of study, three times in lab experiment studies, two times in field experiment studies, five times in modelling/simulation studies and four times in review studies. Also, the kind of equipment or instruments used in the experiments consists of video camera which in some experiments were mounted above the test area, in one of the field experiments the equipment were not described, hence, unknown. In the review studies, there are in general no equipment or instruments used.

With respect to Table 5, the most frequently encountered parameter was the walking speed and as shown in the previous section (3.2 Relationships between the identified parameters) twenty-two out of the fifty identified parameters are considered as fundamental parameters. As Table 5 shows, the most frequently mentioned parameters within the articles included in this analysis are age, body projection area, culture, occupant density, headway, personal space, step size, vison and weight. Then there are emergency or non-emergency conditions, fatigue, fitness, gender, group size, lateral sway, social relations and step frequency that are a little less frequently encountered. The parameters that were the least encountered are bottlenecks (in particular doors) and openings, emotional state, health status, height and stair gradient.

The kind of equipment or instruments used within the included articles were mainly video cameras mounted on different locations.

3.4 Methodological uncertainty

During this scoping review, even though the framework by Arksey and O'Malley (2005) was used, the review is based on some assumptions. This may have had an impact on the outcome of the scoping review and in this section each step in the scoping review is discussed regarding assumptions and uncertainty. The scoping review followed the following steps:

1. Identifying the research question
2. Identifying relevant studies
3. Study selection
4. Charting the data
5. Collecting, summarizing and reporting the results

In the first step in which the research question was determined, a wide approach was used to be able to identify as many articles as possible. Hence, the uncertainty within this step is considered to be negligible.

During the second step, the list of keywords was made and formed into combinations. To add some keywords and maybe create a couple more combinations may have resulted in more identified studies. Also, three databases were used. To expand the search and use some additional databases may have resulted in a couple more articles as well. In this matter, the database LUBsearch is considered to be of sufficient extent, due to the fact that the license accessible by Lund university is utilized. But to create some robustness in the results the databases PubMed and Scopus were used as complements.

Table 5 - Overview of the research field with respect to the identified parameters, type of study and equipment used

Equipment used ■ = Video camera × = Video camera (recorded from above) • = Non-experimental study ◆ = Unknown ★ = Video camera (recorded from the side, in height of the chest)	**Observational study**	**Lab experiment**	**Field experiment**	**Modelling/simulation**	**Review**
Acceleration time		××	×	××	
Adaption time		××	×	×	
Age	■	■××	■◆	■••••	••••
Balance		×		•	•
Body mass index, obesity, weight, body weight		×◆	■×◆	■×•	••
Body projection area		×××★	■×	■×•★	••
Body size		×××◆		××	
Bottlenecks (in particular doors), openings					••
Clothing	×	◆	■	■	•
Cooperative behavior			×		
Crowd composition		××			•
Culture	■×	■×××	◆	•××	••
Occupant density		■×××××◆ ★	×◆★	■×•★	••••
Emergency or non-emergency		×◆	×	×•	••
Emotional state				•	•
Fatigue		◆	■×★	■••◆	•
Fitness			■◆	■••	
Gender		××	×◆	••	••
Group movement, group formation	■×	■×	■■×	■■•	•
Group size	■		■×	■•	••
Headway, inter-person distance, safety margin	■	■■×××××× ★	×	■■××★	••••
Health status			■	■•	
Height, length		■××		■	
Horizontal surface		◆◆	◆	◆	•
Lateral sway, lateral oscillation		××××		×	••
Leg extensor power			◆		
Personal space	■×	■■××××	×	■■×××••	••
Social relations		××	×	×	•
Stair gradient		×	◆		
Stairs		×◆◆	◆★	◆	•
Step frequency		■×	◆	■×•	
Step size, step length, stride length	×	■×★	◆	■×••••★	•
Torso rotation				•	•
Vision	■	××	×★	×•	•••
Walking speed	■	■■×××××× ××◆◆★	■××◆◆★	■■■×××••• •••◆★	•••••
Wall distance, obstacle avoidance		××	×	××•••	•
Weather (outside)					••

During the import of the identified articles into EndNote, all articles couldn't be imported. The reason for this is unknown but in the worst case this error may have caused loss of relevant studies.

The third step of the scoping review is perhaps the phase in which most of the uncertainty is located. During the exclusion phase, the created criteria were used but the final decision if the article should be included or excluded was up to the author of this thesis. To make this phase more robust and reduce the uncertainty within, it would be beneficial if the same process were made by another person as well and see if the same decisions were made regarding the exclusion and inclusion. Alternatively, that two or more persons did this phase together and discussed during the exclusion or inclusion decisions. This is common practice in published scoping reviews to uphold rigorous research standards. Due to the systematic recording of what articles were excluded at each stage of the current scoping review process, a second researcher would be able to undertake a verification process.

Also, only seventy-five of the articles remaining to the "exclude by full text"-phase were taken for further analysis within this thesis. The other articles which were categorized into Rating 2 and Rating 3 may identify additional parameters and should be analyzed in the future to receive the whole picture regarding the crowd movement.

In step four and five, the articles were read through and the relevant information was extracted. It would probably be beneficial even in this phase that more than one person read through the articles to ensure that the content of the article was correct perceived. This uncertainty has been reduced as far as was possible by the author in terms of reading the articles very carefully and several times.

Finally, the analysis in the fifth stage are based on the assumption that the parameter "walking speed" is of greatest relevance to describe the crowd movement. This assumption is based on the fact that this parameter was the most frequently encountered within the literature and that almost all of the identified parameters in some way were related to the walking speed.

4 Conclusions

Within the thirty-five articles that were taken for further analysis, a total of fifty parameters were identified. After the analysis of the relationships between those parameters, twenty-two parameters were found to have an impact on crowd movement and are considered as fundamental parameters. Those parameters are:

- Age
- Body projection area
- Bottlenecks, openings
- Culture
- Occupant density
- Emergency or non-emergency
- Emotional state
- Fatigue
- Fitness
- Gender
- Group size
- Headway
- Health status
- Height
- Lateral sway
- Personal space
- Social relations
- Stair gradient
- Step frequency
- Step size
- Vision
- Weight

It should be noted that the other identified parameters are not shown to be negligible, but that those twenty-two parameters presented above are considered fundamental. Also, the methodology used, is considered to be successful, due to the wide number of identified parameters.

5 Future research

In this section, suggestions of future research are to be presented with respect to the information that may be found in Appendix III – Data extraction sheet, as well as the outcome of the analysis.

The impact of cultural background has been highlighted to need further investigation by Almejmaj et al. (2014) and Lv et al. (2013) and Song et al. (2013). Almejmaj et al. (2014) refers to the effects of gender segregation, which would be put into the category "culture" in this thesis. Lv et al. (2013) refers to the relation between headway and walking speed and how this relationship is affected by cultural background. Also, the movement in stairs may be affected by cultural background and is in need of future research (Song et al., 2013). However, in this thesis it's suggested that the main parameter that influences the movement in stairs are the stair gradient so maybe the stair gradient is the parameter that should be considered during future research. The impact of personal space and occupant density upon the walking speed are highlighted to need further investigation as well (Almejmaj et al., 2014).

The relationship between walking speed and headway is said to need further investigation by (Duives et al., 2015), (Lv et al., 2013) and (Shuchao et al., 2016). (Shuchao et al., 2016) stresses that especially the impact of age should be considered. The impact of age upon the crowd movement has been highlighted by Thompson et al. (2015) as well.

According to Ding et al. (2016), Muhdi et al. (2006), Ronchi et al. (2016) and Thompson et al. (2015) is further investigation about the impact on fatigue needed. Thompson et al. (2015) describes that gait biomechanics with parameters such as leg length, stride length, lateral sway and gait patterns need to be considered in future research because they may have an influence on the crowd movement. However only stride length and lateral sway were found within this thesis. The need of additional research about the lateral sway is stressed by Juan et al. (2017) as well.

Muhdi et al. (2006) and Thompson et al. (2015) mentions that health status need further investigation. Thompson et al. (2015) also states that the impact of obesity should be investigated further. Spearpoint and MacLennan (2012) says that the influence of body size should get some future attention as well.

Other parameters that needs further investigation are the emotional state which has been mentioned by Duives et al. (2015), gender mentioned by Muhdi et al. (2006) and social relations suggested by Bode et al. (2015).

The last two parameters that were mentioned within the literature to need further investigation were "wall distance, obstacle avoidance" mentioned by W. Ma et al. (2015) and if there is emergency or non-emergency conditions, which was suggested by Zhao et al. (2017).

The parameters that are considered to need further investigation with respect to the analysis are; culture, gender, emotional state, cooperative behavior, wall distance or obstacle avoidance, bottlenecks or openings, headway, acceleration time, torso rotation, body size, health status and stair gradient. Those parameters have been highlighted within the literature and during the analysis regarding the relationships, those parameters has been shown not to be fully investigated. Since stair gradient, health status, emotional state, culture, bottlenecks or openings, as well as headway are considered to be fundamental parameters, the suggestion is to focus the primary research around those parameters.

Since the stair gradient only were encountered within two out of the thirty-five articles, this parameter need to be further investigated to understand it's influence on the crowd movement.

The same applies to the health status, which were encountered three times within the literature. Especially the relationship between health status and fatigue should be further investigated but there might be relationships that haven't been discovered within this thesis.

The relationship between emotional state and walking speed has been highlighted earlier in this report as well. However, this relationship wasn't explained which means that the next step is to fully investigate the influence of emotional state upon the walking speed. Since the emotional state only were encountered within two of the included articles there seems like not research has been made under the current topic. Which implies that there might be more relationships between the emotional state and crowd movement that haven't been discovered yet. Hence, this may be a very important parameter to fully investigate.

The influence of culture has been highlighted within several of the encountered articles. The know relationships that should be investigated in the first place are the influence of culture on the walking speed as well as the occupant density. This are the relationships that were mentioned within the literature but the parameter might have unknown relations to the movement within a crowd which are yet to discover.

Most of the existing research regarding the influence of the parameter "headway", are obtained through single-file experiments, but within the literature there were an indication that those results were different in a two-dimensional situation, i.e. the data obtained from the single-file experiment may not be valid for other situations that just single-file movement. Since this indication were discovered and the parameter has been found to be fundamental, some future investigation should pay attention to the headway. The influence of bottlenecks or openings, mainly doors, has been highlighted as well but the interaction between people and this kind of obstacles has not been fully investigated and some uncertainty about the outcome are present.

With respect to the reasoning above, the parameters that are suggested to need some further investigation are:

- Bottlenecks (in particular doors), openings
- Culture
- Emotional state
- Headway
- Health status
- Stair gradient

This thesis forms a part of the study "Crowd safety: prototyping for the future". The parameters that have been highlighted within the thesis will be specifically considered in future experimentation and investigation.

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Appendix I – Keywords and combinations

A total of twenty-three keywords were used, the used keywords were:

- Biomechanics
- Crowd
- Crowd dynamics
- Crowd flow
- Crowd movement
- Crowded spaces
- Evacuation
- Gait
- Interperson distance
- Inter-person distance
- Locomotion
- Modelling
- Motion
- Movement
- Pedestrian dynamics
- Pedestrian flow
- Perception-time
- Personal space
- Reaction time
- Response time
- Sensorimotor
- Simulation
- Walking

Those keywords were then formed into the following four combinations which were used during the search on the databases LUBsearch, PubMed and Scopus:

Search 1

[Biomechanics OR Locomotion OR Motion OR Movement OR Walking OR Gait] AND [Crowd OR "Crowd dynamics" OR "Pedestrian flow" OR "Pedestrian dynamics" OR "Crowd movement" OR "Crowd flow" OR "Crowded spaces" OR Evacuation] AND [Modelling OR Simulation]

Search 2

[Biomechanics OR Locomotion OR Motion OR Movement OR Walking OR Gait] AND [Crowd OR "Crowd dynamics" OR "Pedestrian flow" OR "Pedestrian dynamics" OR "Crowd movement" OR "Crowd flow" OR "Crowded spaces" OR Evacuation] AND ["Interperson distance" OR "Inter-person distance" OR "Personal space"]

Search 3

[Biomechanics OR Locomotion OR Motion OR Movement OR Walking OR Gait] AND [Crowd OR "Crowd dynamics" OR "Pedestrian flow" OR "Pedestrian dynamics" OR "Crowd movement" OR "Crowd flow" OR "Crowded spaces" OR Evacuation] AND [Modelling OR Simulation] AND ["Interperson distance" OR "Inter-person distance" OR "Personal space"]

Search 4

[Biomechanics OR Locomotion OR Motion OR Movement OR Walking OR Gait] AND [Crowd OR "Crowd dynamics" OR "Pedestrian flow" OR "Pedestrian dynamics" OR "Crowd movement" OR "Crowd flow" OR "Crowded spaces" OR Evacuation] AND [Sensorimotor OR "Reaction time" OR "Response time" OR "Perception-action"]

Appendix II – EndNote

This appendix is a digital version available for download. To access the appendix the following link may be used:

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On the web page, which the above-mentioned link is connected to, a topic box called "Related materials" may be found. In this box, there is a link called "Appendix II – EndNote". By using this link, the EndNote library is downloaded and can be accessed. Note that the reference managing program *EndNote* must be installed on the used computer to be able to open the EndNote file.

Appendix III – Data extraction sheet

This appendix is a digital version available for download. To access the appendix the following link may be used:

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On the web page, which the above-mentioned link is connected to, a topic box called "Related materials" may be found. In this box, there is a link called "Appendix III – Data extraction sheet". By using this link, the Excel sheet is downloaded and can be accessed. Note that the program *Microsoft Excel* must be installed on the used computer to be able to open the Excel sheet.