PRESCRIPTIVE AND ACTUAL OCCUPANT LOAD OF BUSINESS PREMISES IN FINLAND BEFORE AND DURING COVID19

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Prescriptive and actual occupant load of business premises in Finland before and during covid19

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Abstract
The purpose of this thesis was to study the correspondence of occupant load factors determined by the guidance document of Finnish National Building code and the real occupant loads measured from shopping malls. The correspondence of occupant load factors determined according to Finnish National Building Code were compared with the occupant load factors determined in other national and international building codes. In addition, the impact of Covid19 pandemic to the evacuation was studied. The data was collected from shopping malls that were located around Finland. The years where the data was asked were 2019 and 2020 so that comparison before and during the pandemic could be carried out. As a result, it was observed that the occupant loads that were determined with the occupant load factors overestimated the occupant load in shopping malls quite significantly. When the correspondence of occupant load factors was examined, it was observed that the occupant load factors are determined much more specifically to specific building use in other countries than in Finland. Therefore, occupant load factors that were determined in the guidance document of Finnish National Building Code did not correspond very well with the real occupant loads. Lastly the impact of Covid19 pandemic to the evacuation was studied. Firstly, it was noted that even though the occupant loads in shopping malls decreased a lot when the pandemic began, they recovered in a couple months close to the levels before the pandemic. It was also observed that if the occupants are physical distancing during the evacuation, it will increase the evacuation time specially if they get stuck in the queues on their way out of the building.

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ABSTRACT

The purpose of this thesis was to study the correspondence of occupant load factors determined by the guidance document of Finnish National Building code and the real occupant loads measured from shopping malls. The correspondence of occupant load factors determined according to Finnish National Building Code were compared with the occupant load factors determined in other national and international building codes. In addition, the impact of Covid19 pandemic to the evacuation was studied. The data was collected from shopping malls that were located around Finland. The years where the data was asked were 2019 and 2020 so that comparison before and during the pandemic could be carried out. As a result, it was observed that the occupant loads that were determined with the occupant load factors overestimated the occupant load in shopping malls quite significantly. When the correspondence of occupant load factors was examined, it was observed that the occupant load factors are determined much more specifically to specific building use in other countries than in Finland. Therefore, occupant load factors that were determined in the guidance document of Finnish National Building Code did not correspond very well with the real occupant loads. Lastly the impact of Covid19 pandemic to the evacuation was studied. Firstly, it was noted that even though the occupant loads in shopping malls decreased a lot when the pandemic began, they recovered in a couple months close to the levels before the pandemic. It was also observed that if the occupants are physical distancing during the evacuation, it will increase the evacuation time specially if they get stuck in the queues on their way out of the building.

ABSTRAKTI (ABSTRACT IN FINNISH)

Opinnäytetyö tarkoituksena on tutkia kuinka kauppakeskuksista mitatut maksimi henkilömäärät vertautuvat henkilömääriin, jotka on laskettu Ympäristöministeriön asetuksen rakennuksen paloturvallisuudesta perustelumuistiossa annetuilla arvoilla, joita voidaan käyttää, mikäli rakennuksen henkilömäärä ei ole ennalta tiedossa. Lisäksi tutkittiin, miten perustelumuistiossa määritellyt arvot vastasivat muissa maissa ja kansainvälisissä standardeissa määriteltyjä arvoja sekä koronaviruspandemian vaiktusta rakennuksen henkilötiheyteen. Työtä varten tietoja kauppakeskusten henkilömääristä kerättiin ympäri Suomea olevista kauppakeskuksista. Tietoja kerättiin vuosilta 2019 ja 2020, jotta vertailua ennen pandemiaa ja pandemian aikana voitiin toteuttaa. Tutkimuksessa havaittiin, että perustelumuistion arvojen perusteella määritellyt henkilömäärät ovat huomattavasti korkeampia verrattuna todellisista kauppakeskuksista mitattuihin arvoihin. Lisäksi huomattiin, että arvot henkilömäärän arvioimiseksi on ulkomailla määritelty paljon tarkemmin tiettyä rakennuksen käyttötarkoitusta ajatellen. Koronaviruspandemian ja rakennuksen henkilömäärään liittyen havaittiin, että vaikka rakennusten maksimi kävijämäärät aluksi putosivat huomattavasti, ne palautuivat muutamassa kuukaudessa lähelle pandemiaa edeltäviä määriä. Poistumista tutkittaessa simulaatioilla, havaittiin että turvaetäisyyksien pitäminen poistumisen aikana lisää poistumisajan pituutta, erityisesti jos rakennuksessa olijat jäävät jumiin ruuhkiin poistumisteiden eteen.

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1. INTRODUCTION

The aim of this thesis study was to investigate the correspondence of occupant load factors defined by the guidance document of the Ympärisöministeriön asetus rakennuksen paloturvallisuudesta (Decree of the Ministry of the Environment on the Fire Safety of the building) and the occupant loads that are measured from real retail buildings in Finland. The other purpose was to investigate the impact of the Covid19 pandemic to the occupant load during the pandemic.

The thesis project was made for KK-Palokonsultti Oy which is Finnish fire consultant company that specializes in performance-based fire safety design. The need for the thesis project arose since the occupant load factors provided by guidance document of the Ympäristöministeriön asetus rakennuksen paloturvallisuudesta are used as a reference when the occupant load of the buildings is designed, and the occupant load is not known. However, based on practical knowledge, it seemed that the occupant load factors provided by the guidance document seemed too dense, and they caused challenges in the egress design. This practical knowledge is backed up by the fact that in the earlier research from other countries it is observed that regulation based occupant load factors are often too conservative and poorly justified (De Sanctis et al., 2019). The alternative data can also be used to determine the occupant load if it is well justified. Therefore, the study for the correspondence of occupant load factors and real occupant loads were needed in order to get alternative data on the occupant loads in Finnish retail buildings.

In addition, since the thesis was made during the Covid19 pandemic the questions arise on how the pandemic situation affects the occupant load, since the people are advised to avoid social contacts and keep physical distance towards other people. Enlightened guess that was predicted was that the occupant loads in public assembly and business premises would decrease, since the the governments around Europe announced restrictions and suggestions for the public gatherings. Even though the decreasing of occupant load was a logical conclusion, there was no researched data on what kind and how large effect the pandemic will have on the occupant load.

Therefore, the goal of this thesis is to provide information about the actual occupant loads that are measured from real business premises from Finland and find out if the occupant load factor for assembly and business premises would correspond with the actual occupant loads in business premises. The second goal is to find out how large is the impact of Covid19 pandemic on the occupant load in the buildings and how it should be considered when the evacuation design is made. Therefore, three research questions are placed where this thesis project aims to answer. The research questions are:

1. How the occupant load factor determined by the guidance document on Finnish fire safety regulation corresponds with the other national and international standards?
2. How the regulation-based occupant load factors correspond with the occupant loads measured from real retail premises?
3. What is the impact of Covid19 pandemic to the occupant load and how should it be considered in the egress design?

When the occupant load factors are compared all the usage categories that are determined by the Finnish regulation, Ympäristöministeriön asetus rakennuksen paloturvallisuudesta, are included in the comparison. However, when the correspondence of occupant load factors and real occupant loads and the impact of the pandemic to the occupant load is studied the scope is limited and contains only the business premises.

The first part of the thesis contains a summary of the codes, standards and codes of practice that are used in occupant load factor comparison and after that there are literature review were the background knowledge is gathered together of the earlier research related to the occupant load factors and occupant loads. In the second part of the literature review the Finnish National Building Code is introduced and the comparison of the occupant load with other national and international building codes, standards and codes of practice is made.

After the literature review, the methodology is presented for the comparison of occupant load and occupant load factor and comparison of occupant loads before and during covid where all the different steps that are used are presented. After the methodology part results are introduced for the research questions two and three. In the discussion part the final answers are provided for the research questions where the answers are justified either by the results that are found from this study or in earlier research. Also, the limitations and the further research topic are discussed. Lastly the key findings are presented in the conclusions part.

2. NATIONAL BUILDING CODES, STANDARDS AND CODES OF PRACTICE

In this study several national and international building codes, standards and codes of practice are studied to make a comparison of occupant load factors from different countries. The Finnish National building code is used as a basis and it is compared with National building codes, standards and codes of practice of the UK, Sweden, Ireland and Italy. These countries were chosen mainly because their national building codes, standards and code of practices were in English, Finnish or in Swedish. The original versions of the studied documents from the UK and Ireland were in English. The official version of the Finnish National Building Code is in Finnish and in Swedish and the official version of the Swedish National Building Code is in Swedish. Since the official version of the Italian fire safety regulations and instructions was in Italian, only its English translation was used. The reason to choose the International Building Code 2018 and the standard NFPA 101: Life Safety Code was basically their availability since they were found in English language. The country of the National Building Code, code of practice or standard, is the name and the acronym that has been used in this Thesis are presented in table 1.

Table 1. National and international codes and standards and their acronyms

Country	Code, Standard or Code of practice	Acronym
Finland	Ympäristöministeriön asetus paloturvallisuudesta	848/2017
UK	Fire safety in the design, management and use of buildings: code of practice	BS9999:2017
UK	Approved Document B: Fire safety	ADB
Sweden	Boverkets Författningssamling (2011:6) - Boverkets byggregler (18)	BFS 2011:6 - BBR18
Ireland	Building Regulations 2006, Technical Guidance Document B - Fire Safety	TGD B
Italy	Ministero Dell'intero Decreto 18 ottobre 2019	D.M. 18.10.2019
International	NFPA 101: life safety code 2021	NFPA 101
International	International Building Code (2018)	IBC 2018

3. LITERATURE REVIEW

The literature review consists of two parts. The first part concentrates on the theory that has been studied about occupant loads, occupant load factors and their relationship. In the first part, the terms occupant load and occupant load factor are defined and what has been earlier researched is studied. Also, the way how the occupant load factor can be measured and how occupant loads and occupant load factors can be used in legislation are introduced. In the second part occupant load factors from Finnish standards are investigated and compared with other national standards if correspondences with other countries or international standards can be found.

3.1 Occupant load and occupant load factor

When the fire engineering design is made, it is often important to be able to define the occupant load of the building. The occupant load means the number of occupants that the building accommodates at the same time. One of the most common reasons why the occupant load needs to be estimated for fire safety design is when required safe egress time is calculated for a performance-based design project. Required safe egress time is the time that it takes from ignition to evacuate the building. It is called with the term RSET and it consists of detection time, notification time, pre-movement time and evacuation time (Gwynne & Rosenbaum, 2016). Other reasons can be that in some prescriptive design codes, like in the Finnish decree 848/2017, occupant load is used to set fire safety measures like smoke alarms, sprinklers, etc, or in a risk-based approach, occupant load is defined so that the number of expected fatalities can be estimated. (De Sanctis et al., 2014). It is important to note that the occupant load should not be mixed with the loads that are determined in Eurocodes to describe the loads that cause stress to the load-bearing structures of the construction. The load caused by the weight of occupants is included in the imposed loads. (British Standards Institution, 2010.)

In general, the Occupant load includes the number of people that are in the building at the same time, but there is not a universal definition for the occupant load (Spearpoint & Hopkin, 2018). The BS9999:2017 and ADB share the same definition for occupant load. According to these codes and standards it is either the maximum number of people that the room, building, or storey is designed to hold or in other buildings than dwellings, it is the number of people calculated by dividing the area by a floor space factor. When the area is measured, counters and display units should be included in it, but stair enclosures, lifts, sanitary accommodations, and other fixed parts of the building should be excluded. The Finnish decree on the Fire safety of the buildings gives a very similar definition: “The highest number of occupants intended to be present in an evacuation area.” The guidance document of the decree provides occupant load factors and that can be used if the occupant load in a building is not known. The difference to the British Standards and ADB is that, when using occupant load factors, the guidance document does not exclude any areas that should not be taken into account.

Occupant load is often determined from occupant load factors that are often described in prescriptive codes or from international standards (Spearpoint & Hopkin, 2018). The occupant load factors are often specified by unit area per person (m^2/person) or vice versa (person/m^2) (Spearpoint & Hopkin, 2020). When occupant load is calculated according to the standard used, the area of the building is divided by the occupant load factor. The area can be either gross floor or net floor area, but that depends on the standard that is used. In general, it is also considered that size, use, and location of the rooms inside the building affect the actual occupant load (De Sanctis et al., 2019). The occupant load in commercial premises is in normal daily use much smaller than the design value in prescriptive codes (Charters et al., 2002). In general, this is considered as conservative assumption, because evacuating more people often takes more time. If the evacuation system is designed for a higher number of people, it can be assumed that evacuation will be faster with less people so using the higher occupant load increases the safety margin of the design (Spearpoint & Hopkin, 2018). The issue with assessing the occupant load with occupant load factors from prescriptive code is that it is often unclear on which kind of data or estimations the numbers in codes or standards are based on, especially since it has been studied that sometimes the values are not realistic (De Sanctis et al., 2019). This phenomenon is identified and called an issue of magic numbers. It means that regulations and codes often provide tables and values for design values but the justification and reasoning for these numbers are often left out from the documents. This makes it impossible for the user to know how the specific values are determined and to evaluate if the values correspond with the user's situation. It can be argued that the need for transparency with the values is not important when performing prescriptive design; it becomes important when applying performance-based design. When the basis and the derivation of the values is explained it can be evaluated if the value can be applied in the user's situation or if it needs to be modified based on newer information. This way it is also possible to determine if the value is completely outdated. Additionally, occupant load can be estimated from measured values. (Gissi et al., 2017; Spearpoint & Hopkin, 2018).

The way different codes, standards or codes of practices determine the occupant load factor may vary. The simplest method is to use uniformly applied values, which means, there is only one single value for the entire building. The values can be given for different occupant categories, but generally, only one number is used in one building. Another alternative to specifying the occupant load is to specify the occupant load based on floor level, where the values vary based on the factor of floor level or based on occupant type where the factor is specified for mercantile activities. (Spearpoint & Hopkin, 2018).

3.2 Measuring occupant density factor from arrivals and departures

The occupant load factor is the predetermined occupant density value that is used in the regulation to estimate the occupant load in buildings with different intended use when the occupant load is not known. Occupant density can be presented either persons per square meter or square meter per person. In the guidance document of the Finnish decree on the Fire safety of the buildings occupant load factors are given in persons per square meter (Ympäristöministeriö, 2017). The values given in the guidance document are translated into m^2/person, since the most reference codes, standards and codes of practices are in m^2/person, it is easier to carry out the comparison. The two ways of calculating the occupant density are given in the following equations 1 and 2:

Persons per square meters: $d = \frac{p}{af}$ (Equation 1)

Square meters per persons: $d = \frac{af}{p}$ (Equation 2)

- d = Occupant density (m^2/person or person/m^2)
- p = Number of occupants
- af = area of the building (m^2)

The number of occupants is simply the highest number of occupants, but there can be variation how the area that is used in the calculation is determined in different codes, standards and codes of practices. Common ways to determine the floor area, is to use either gross or net area. Gross area or gross floor area means the total floor area of the building where the area is measured according to the external surface of external walls (Kiinteistösanasto. TSK 4, 1984). The net floor area is measured according to the internal surfaces of the walls and other necessary structures of the building like load-bearing columns (Kiinteistösanasto. TSK 4, 1984). It should be pointed out, that sometimes the codes, standards and codes of practices might determine areas that are excluded from the determined gross or net floor area. Good example of this is BFS 2011:6 - BBR18 where the area of the furniture is subtracted from the ne floor area.

When the occupant density is presented in persons per square meters, the actual occupant load is higher when the value of occupant load factor is higher. It is because the value describes the number that shows how many people are in the area of one square meter. When the occupant density is presented in square meters per person, the number describes how much space one occupant has inside the building. When the space gets smaller it means that the actual occupant load is higher. Therefore, when the occupant load factor is presented in square meters per person, the smaller the value is, the higher is the occupant load.

The number of people varies all the time as people are coming in and going out from the transient space, so the occupant density is in constant change. The number of people inside the room is often assessed from then occupant counter data, with two methods.

In the first method, the occupant load is calculated by counting people coming and leaving the building as equation 3. The number of people inside the building at the specific moment of time is then calculated by deducting the number of departures from the number of arrivals. In order to use this method, the premise must be equipped with the occupant counting system, that is able to recognize who is going in and who is coming out from the building. Another way is to use this system, where the flow of people goes only one way, and people exit from a different place than where they come in. (De Sanctis et al., 2019).

$$P(t) = NA(t) - ND(t) \quad \text{(Equation 3)}$$

where:

- P = Number of people
- NA = Number of arrivals
- ND = number of departures

3.3 Measuring the occupant load factor based on dwell time

The second method to calculate the occupant load factor is based on dwell time. Dwell time is defined as the time that person spends in the defined space, and it is individual for each customer. In this method each time a customer walks into the premise the cumulative number of arrivals is increased by one. The arrival time of the customer is recorded since it is needed to estimate the departure time of the customer. The departure time of the customer is then calculated:

$$tD = tA + \tau \text{ (Equation 4)}$$

Where:

- tD = Time of departure
- tA = Time of arrival
- τ = Dwell time of the customer

The time of departure is then recorded, and each departure is added to the cumulative number of arrivals. The number of occupants at the premise is then calculated by deducting the cumulative number of departures from a cumulative number of arrivals at a specific time.

In order to use this method, systems must be able to at least count the number of persons arriving and departing at the premise, but the so-called tracking system is better since it can measure the dwell time for each individual. The benefit of this method is that time of arrival or departure is often available, and the dwell time can be estimated with the assumptions or with former research data. (De Sanctis et al., 2019).

3.4 Estimating the occupant load from the number of sales

The third method to assess the number of people inside the retail store is based on the fact that the number of sales can be associated with the customers leaving the store. However, this method is questionable, because when people are shopping together, it often leads to one sale per group. This is the reason why the number of sales does not represent the actual number of departures. In the earlier research, it was assumed that 50% of customers are alone, 35% are in a group of two, 10% in a group of three, and 5% in a group of 4 persons. Based on the assumptions that different sized groups only make one sale at the shops the research *Probabilistic assessment of the occupant load density in retail buildings*, has introduced a g-factor that considers the impact of groups when estimating the occupant load from sales (De Sanctis et al., 2014). In order to estimate the number of occupants inside the store the number of sales is multiplied with g-factor. Based on the assumed distribution of the group size the factor of g is stated to be 1.7 in the research. This value does not take into account people who left the shop without buying anything, but the number of these people is assumed to be negligible. (De Sanctis et al., 2014).

This method is based on assumptions made before the Covid-19 pandemic. Since during the pandemic time people are instructed to avoid social contacts and keep distance from others, it can be assumed that the percentages that had been assumed earlier has been changed and the portion of customers in a shop alone could be higher, due to the Covid-19 restrictions.

3.5 Occupant load review from legislation

In the occupant load review firstly the Finnish fire safety legislation and standards are introduced and how occupant load factors are determined. After the Finnish fire safety legislation is introduced, the other national standards are introduced, and how the occupant load factors are determined in the comparison countries. Lastly the comparison is made between the occupant load factors regulated by Finnish legislation and the comparison countries and international standards that are used.

3.5.1 Finnish regulation

The enforcement for Finnish fire safety regulation comes from the Maankäyttö ja rakennuslaki (132/1999) (Land use and building act) as amended by Act 958/2012. Section 117b deals with fire safety. The section states that the building must be designed and built in a way that it is safe in case of fire. The probability of ignition must be limited, the load-bearing structures must be able to withstand the fire for a certain period of time, smoke and fire spread must be limited and people must be able to escape the building themselves or they can be rescued from the building. It is also stated in the section that more detailed information can be given with the decree of the Ministry of Environment.

The occupant load provisions have been regulated in Ympäristöministeriön asetus rakennuksen paloturvallisuudesta (848/2017) (The Decree of the Ministry of the Environment on the Fire Safety of Buildings (848/2017)). There are three main points that affect the occupant load of the building which are namely 1) the intended use of the building, 2) fire classification of the building, and 3) the total door width of the building.

According to the Decree, there are seven different groups for intended uses of the building. Groups are dwellings, accommodation premises, institutions, assembly, and business premises, office premises, production and storage premises, and garages. The usage types are defined in a Decree as follows:

- Dwellings refer to the premises that are used as residences, mostly residential apartments, and leisure apartments.
- Accommodation premises are premises such as hotels and holiday homes that are normally in use for 24 hours. In this usage group, no one is under care or confinement.
- Institutions refer to the premises like hospitals, old people’s homes, and detention centers. Most premises are in use for 24 hours a day and people are under care or confinement.
- Assembly and business premises refers to premises such as restaurants, shops, schools, daycare centers, sports halls, exhibition halls, theaters, churches, and libraries. Generally, the buildings that are used mostly during the day or evening and are often occupied with a large number of people.
- Office refers to the premises that are in daytime use and occupants are familiar with the building.
- Production and storage premises refers to buildings that are associated with industrial activity and storage. These buildings involve ordinary industrial premises, premises for agricultural production, and large warehouses. In this group, occupants are often familiar with the building.
- Garages are facilities that are intended to keep cars and other motor vehicles.

Fire classes are divided into four groups, P0, P1, P2, and P3. P1, P2, and P3 are used when the building is designed on the basis of the classes and numerical criteria that are set out in the Decree. Generally, the fire class P1 needs to meet the strictest criteria regarding the R, E and I and P3 are the loosest where R stands for load-bearing capacity, E stands for structural integrity and I for thermal insulation. P0 is used when a building is designed partly or entirely with performance-based design. Since there are limitations on the size, number of floors, and number of occupants in categories P2 and P3 the shopping malls are usually built according to the fire class P1 or P0, where there are less limitations. The limitations in size and occupant load in P3 class buildings are shown on table 2 and 3:

Table 2. Restrictions regarding the size of P3 Assembly and Business premises.

Building	Number of stories	Max. Height	Max. Gross floor area
One-storey, general	1	9m	2400 m^2 4800 m^2*
Two-story, general	2	9m	1600 m^2 2400 m^2*

* The building is provided with an automatic fire-extinguishing system.

Table 3. Maximum permissible number of persons in P3 Assembly and Business premises

Stories	1	2
Assembly and Business premises, persons	500 (1000*)	150

* The building is provided with an automatic fire-extinguishing system.

The limitation in size and occupant load in P2 class buildings is shown on tables 4 and 5:

Table 4. Restrictions regarding the size of P2 Assembly and Business premises.

Building	Number of stories	Max. Height	Max. Gross floor area
Assembly and Business premises of more than 2 stories	4*	14*	12 0000 m^2*

* The building is provided with an automatic fire-extinguishing system.

Table 5. Maximum permissible number of persons in P2 Assembly and Business premises

Stories	1	2	Over 2*
Assembly and Business premises, persons	No restrictions	250 500*	1000

* The building is provided with an automatic fire-extinguishing system.

The second way to determine the maximum occupant load is based on the total width of the exits of the building. In the Decree section 34, it is stated that the minimum width of an exit is calculated on the basis of the number of occupants evacuation through the exit. With regards to the entire building, it is further defined that the number of occupants of an evacuation area may be distributed between different exits and the widths of the exits added up to obtain the required total width of exits. Normally the exit width must be at least 1200mm. If the number of occupants is less than 60 the second exit can be 900mm. If the number of occupants exceeds 120 persons, the minimum width of the exits must be increased by 400mm for every 60 persons. If the building is a residential building of no more than 2 stories, only one exit of 900mm is accepted. (Ympäristöministeriö, 2017).

If the maximum number of occupants is not known, it can be estimated from net floor areas and with the occupant load factors that are presented in the guidance document of Decree on the fire safety of buildings (Ympäristöministeriö, 2017). The occupant load factors are presented in Table 6. The occupant load factors are presented in the guidance document of Finnish 848/2017 in person/m^2, however, since the most reference codes, standards and code of practises that are used presents the occupant load factors m^2/person the values are translated to m^2/person in occupant load factor comparison.

Table 6. Pre-defined occupant load factors in Finland (Ympäristöministeriö, 2017)

Occupancy	**Occupant load factor (person/m^2) (Net floor area)**	**Occupant load factor (m^2/person) (Net floor area)**
Dwellings, Accommodation premises, Institutions, and office premises	0.1	10
Assembly and business in general	0.4	2,5
Assembly and business, amusement, art, etc.	1	1
Production and storage premises, garages	0.03	33,333

3.5.2 Occupant load factors in selected countries

The occupant load factors vary in national building codes, standards and codes of practice of each country. The occupant load factors are mostly used in regulation in order to determine the occupant load of the building if it is not known before. Then the occupant load is used to determine the exit width of the building. As it is stated before, it is hard to know which kind of data occupant load factor values are based on. In this section occupant load factors from the UK, Sweden, Italy, and Ireland will be introduced.

In the UK occupant load factors can be found from BS9999:2017 and from Approved Document B (ADB). Both documents provide technical guidance and recommendations, but they are not official regulations, so the building projects must fulfill the requirements provided by local building regulations (British Standards Institution, 2017; Great Britain & Department for Communities and Local Government, 2019). In BS9999:2017 occupant load factors are shown in table 7.

Table 7. Occupant load factors according to the BS9999:2017

Use	**Density**	**Population density (m^2/person)**	**example**
Office	High Normal Low	4 6 10	Call Center Open plan office Cellular office
Shop	High Normal Low	2 4 7	Clothing store Supermarket Furniture showroom
Standing area	Very high High Normal Low	0,3 0,5 1 2	People queuing Bar Theatre or cinema foyer Museum / Gallery
Seating area	Normal	0,4	Theatre / Cinema auditorium

* Stair enclosures, lifts, sanitary accommodations and other fixed parts of building structures are subtracted from the area.

In the Approved document B the usage classification is made differently. The buildings are divided into 15 usage groups. Unlike in BS9999:2017 the usage group contains only 1 number and does not consider that the occupant load can vary within the one user group. The usage groups can be quite well detailed in ADB, since there are own user groups for the skating rink or for the kitchen and library but then again, there is only one number for the offices which corresponds with the normal office occupant load in BS9999:2017. The occupant load factors in ADB are shown in table 8.

Table 8. Occupant load factors according to the Approved Document B

Occupancy	**Occupant load factor (m^2/person)**
Standing areas, bar areas, similar refreshment areas	0.3
Amusement arcade, assembly hall, areas without fixed seating	0.5
Concourse or queuing area	0.7
Committee room, Common room, Conference room, restaurant, etc.	1
Exhibition hall or studio	1.5
Skating rink	2
Shop sales area (Supermarkets, department stores, shops for personal services	2
Art Gallery, Dormitory, Factory production area, museum, or workshop	5
Office	6
Shop sales area (trading predominantly in furniture or other bulky goods)	7
Kitchen, library	7
Bedroom	8
Bed-sitting room, halls	10
Storage and warehousing	30
Car park	2/parking

* Stair enclosures, lifts, sanitary accommodations, and other fixed parts of building structures are subtracted from the area.

The occupant load factors in Swedish regulations are defined in Boverkets Författningssamling (2011:6) - Boverkets byggregler (18) that will be referenced later as BFS2011:6 - BBR18. If the occupant load is unknown, the occupant load factors can be found in table 5:333. The occupant load factors are presented as people/m^2net area in the document, but in this thesis, the values will be changed to m^2/person so that comparison is possible.

Table 9. Occupant load factors according to the BFS 2011:6 - BBR18

Occupancy	**Occupant load factor, (m^2/person) net area**
Offices	10
Library*	10
Dance hall	0.4
Classroom	2
Conference room*	1.43
Church	1
Shopping centre, department store, retail store	2
Museum, art gallery	4
Pub, bar	0.333
Restaurant*	Number of seats or 1
Assembly premise (sitting only)	0.59
Assembly premise (standing and sitting)	0.4
Assembly premise (fixed seats)	Number of seats

* Net area can be determined minus the area for loose fittings

The occupant load factors in Irish regulations are provided in the Technical Guidance Document B of Building Regulations 2006. Technical Guidance Document B deals with fire safety. In the document, it states that occupant load is calculated by dividing the area of the room or story by occupant load factor, but the area excludes stairway enclosures, elevators, and sanitary accommodations. Table 1.1 from the document provides the following occupant load factors:

Table 10. Occupant load factors according to the Technical Guidance Document part B

Occupancy	**Occupant load factor (m^2/person)**
Standing area in assembly and recreation building	0.3
Bar, lounge bar	0.5
Restaurant, dining room, meeting room, committee room, staff room	1 / Number of seats
Factory production area, open plan offices	5
Bedroom or study bedroom	8 / Number of beds
Offices and kitchens	7
Storage building, Car park	30 / 2 per parking space

* Area excludes stairway enclosures, lifts and sanitary accommodation.

Occupant load factors in Italian regulations are provided in Gazzetta Ufficiale della Repubblica Italiana in Ministero dell'Interno Decreto 18 ottobre 2019. Annex 1 deals with Technical fire prevention standards. The occupant load factors are provided in table 91 and like the area, the gross surface area is used. In addition, in table 92, there are other criteria on how to determine occupant load in certain facilities.

Table 11. Occupant load factors according to the Ministero Dell'intero Decreto 18 ottobre 2019

Occupancy	**Occupant load factor (m^2/person) Gross area**
Outdoor settings intended for entertainment without seating	0.5
Indoor settings for entertainment. No seating. Fire load >50MJ/m^2	0.5
Settings for entertainment with fire load more than 50MJ/m^2	0.833
Settings for catering	1.43
Settings for educational and laboratory activities (without seating)	2.5
Waiting rooms	2.5
Offices	2.5
Sales settings of small retail business	2.5
Sales settings of medium and large retail business	5
Sales settings of retail business without food section	5
Reading rooms	5
Outpatient clinics	5
Sales settings of wholesome business	10
Sales settings of small retail businesses, with a specific range of non-food goods	10
Residential buildings	20

Table 12. Criteria to determine the occupant load in certain premises according to the Ministero Dell'intero Decreto 18 ottobre 2019

Occupancy	**Criteria**
Public car parks	2 person per parked vehicle
Private car parks	1 person per parked vehicle
Inpatient clinics	1 patient + 2 visitors per bed + staff
Settings with seating or beds	Number of beds + staff
Other settings	Maximum number present

3.5.3 Comparison of occupant load factors in different countries

Comparing the occupant load with the regulations of other countries is not straightforward. Each country has defined its own occupant load factors for different building usage types. This causes an issue because if the usage type is very wide it might contain multiple usage types from other countries. This can be seen very well when comparing the Finnish occupant load factor determined for assembly and business premises. In Finland, this group contains a wide range of different types of buildings whereas in other countries the occupant load factors are defined separately for the specific building. The other problem is, how the areas that are used to define occupant load factor are determined. In some codes, the gross floor area is used and in some codes net floor area is used to determine the occupant load factor. Then there is also variation if there are some specific areas excluded from the total gross or net floor area. Lastly, there can be even variation how the different countries are determined the terms gross floor area and net floor area.

The occupant load factors are compared in Appendix 1. To facilitate the comparison, there are seven graphs that are divided according to Finnish usage groups. The yellow column illustrates the occupant load factor in Finland in a specific usage group. The other columns illustrate the occupant load factors from other countries that would correspond to the Finnish usage group.

The occupant load factor for dwellings is only determined in Italian D.M. 18.10.2019 alongside with Finish 848/2017. It can be observed that the occupant load factor in 848/2017 (10 m^2/person) is stricter than the occupant load factor determined in D.M. 18.10.2019 (20 m^2/person). (Direzione centrale per la prevenzione e la sicurezza tecnica, Ufficio per la prevenzione incendi ed il rischio industriale & Ponziani, 2019; Ympäristöministeriö, 2017)**.**

The same issue as with dwellings can be seen in usage group garages where occupant load factor is defined only for Finland and Ireland. The occupant load factors in both countries are almost the same. The occupant load factor according to the 848/2017 is 33.3 m^2/person and according to TGD B 30 m^2/person. However, the regulation of different countries offers a way to estimate the occupant load in car parks. Generally, the occupant load in car parks is estimated to be 2 people per parking space. This method is used in ADB, BFS 2011:6 - BBR18, and in TGD B, it can be used as an alternative method in estimating the occupant load. According to the D.M. 18.10.2019, the occupant load in public car parks is estimated similarly, 2 people per parking space. For private car parks, the occupant load is estimated to be 1 person per parking space.

When accommodation premises are compared it can be seen that the values can be compared with three values from ADB and one value from Technical Guidance Document part B. In ADB the premises that would correspond with the accommodation premises determined by 848/2017 are dormitory, bedroom and bed-sitting room and in Technical Guidance Document part B corresponding values are determined for bedroom. The occupant load factor determined in 848/2017 for accommodation premises is 10 m^2/person. When compared with the ADB the value of bed-sitting room corresponds with 848/2017 but the occupant load factors for bedroom (8 m^2/person) and dormitory (5m^2/person) are stricter. The values that are determined for bedrooms according to the ADB and TGD B correspond with each other.

In institutional buildings, the occupant load is the same as in accommodation premises. The occupant load factors can be compared again with the bedrooms and bed-sitting rooms from ADB and TGD B. According to D.M. 18.10.2019, the occupant load can be determined with the occupant load factor for outpatient clinics and with the number of beds for the inpatient clinics.

The occupant load factors for offices have been defined for all standards that have been used in the comparison. In the BS9999:2017 three values have been defined for three different types of offices. The values are 4 m^2/person for high occupant load offices like call centers, 6 m^2/person for medium occupant load offices like open-plan offices, and for low occupant load offices 10 m^2/person and an example is a cellular office. The occupant load factor according to 848/2017 and BFS2011:6 - BBR18 corresponds with the low occupant load office. In TGD B, the defined occupant load factor for offices is defined to be 7 m^2/person, so the occupant load is estimated to be a little higher. The occupant load factor determined in ADB corresponds with the value that is determined for Open plan offices in BS9999:2017. In TGD B, the occupant load factor is defined for open plan offices as well, and it is 5 m^2/person, so occupant load is expected to be slightly higher than according to BS9999:2017. The highest occupant load factor in offices is determined with the D.M. 18.10.2019, where the occupant load factor for offices is 2.5 m^2/person.

One of the user groups that is used in Finland is production and storage buildings. The occupant load factors that match with this user group can be found in ADB and TGD B. The occupant load factor that is used in 848/2017 for production and storage buildings corresponds well with the values that are determined for the storage buildings in TGD B and in ADB. The occupant load factor for storage and warehouses in these regulations is 30 m^2/person whereas according to the 848/2017 it is 33.3 m^2/person. However, since the usage group according to the 848/2017 contains both production and storage areas, it does not correspond well with the occupant load factors that are determined for production areas provided in ADB and TGD B. ADB and Technical Guidance document part B corresponds well with each other since the occupant load factor for production areas is determined to be 5 m^2/person in both documents. However, this occupant load factor is way stricter than the occupant load factor determined by 848/2017.

The most complex usage group is the assembly and business premises. In 848/2017, this usage group is divided into two groups: Assembly and business premises, in general, and Assembly and business premises, Amusement, art, etc. However, it has not been further explained, what premises belong to the group of “in general” and what belongs to the group “Amusement, art, etc.” This means that assumptions are made to identify correspondence there between general assembly and business premises and shops, schools, libraries, sports halls, and daycare premises. The Assembly and business premises of amusement and arts refers to the restaurants, bars, theaters, museums, churches, exhibition and conference halls, and standing areas where a huge number of people gather together. The issue with comparing occupant load factors of assembly and business premises is that, even if it is split into two groups, the groups contain a wide spread of different types of premises, and it is questionable if one single value for the occupant load factor can be used.

The occupant load factor in a general assembly and business premises in Finland is determined to be 2.5 m^2/person. The group is compared with 14 different values of occupant load factor from BS9999:2017, ADB, BFS2011:6 - BBR18, and D.M. 18.10.2019. The lowest values correspond quite well with the occupant load factor of 848/2017 since the occupant load factor of 2 m^2/person can be found in clothing stores in BS9999:2017, high-occupant load shop sales areas in ADB, and in classrooms, shopping malls, and retail stores in BFS2011:6 - BBR18. In addition, according to

D.M. 18.10.2019 in small retail businesses, the occupant load factor is exactly the same as in 848/2017. However, since the usage group according to the 848/2017 contains a wide spread of different types of buildings, one determined occupant load factor does not correspond well with all the building types that other countries have determined. For example, the occupant load factor is 10 m^2/person for libraries according to the BFS2011:6-BBR18 and for small retail business with non-food goods according to the D.M. 18.10.2019.

The same issue can be observed in the usage group of assembly and business premises for amusement and art etc. The occupant load factor in this group is defined to be $1m^2$/p. When this occupant load is compared with the other national standards it can be observed that other countries have determined multiple values for more precise building types. The values according to the 848/2017 corresponds with some values, but with other values it does not, since the usage group contains so wide spread of different types of buildings.

3.5.4 Comparison of Finnish occupant load factors and NFPA 101 and IBC 2018

The occupant load factors are defined also in international standards. For this thesis, the international standards used are NFPA Life safety code 101 and International Building Code 2018.

The comparison between Finnish regulation, NFPA 101, and the International Building code is made in table 13. The first aspect to notice, is that both NFPA 101 and IBC2018 have not defined occupant load factors for offices and garages. For dwellings, it can be noted that both international standards have higher occupant load factors for residential buildings than in the Finnish National Building Code.

In accommodation premises, the occupant load factors are defined in NFPA 101 jointly for hotels and dormitories and in the IBC2018 for residential buildings and dormitories. In Finland the occupant load factor is 10 m^2/person in NFPA 101 for hotels and dormitories the occupant load factor is 18. Interestingly the International Building Code shows that the occupant load factor for dormitories is 4.65 m^2/person.

For institutional buildings, assembly and business premises, and production and storage buildings it can be seen that in international standards multiple occupant load factors are defined that would fall into one usage group in Finland. In institutional buildings, the occupant load factor matches closely with the sleeping areas and detention centers from NFPA 101 and with sleeping areas and outpatient areas in IBC2018. In NFPA 101 Board and care, Ambulatory healthcare and inpatient areas have higher occupant load factors whereas in International Building code inpatient areas have higher occupant load factors. This means that even if in Finish regulation, there is only one number for institutional buildings, the number is on the stricter end of the spectrum when occupant load is estimated.

Assembly and business premises are divided into two groups in Finnish regulation. The first group contains general assembly and business premises where the occupant load factor is 2,5 m^2/person and the second group is assembly and business premises which are used for amusement, art, etc, where the occupant load factor is $1m^2$/p. In the NFPA 101 there were multiple occupant load factors defined that would correspond with the determined group of “general assembly and business premises”. In NFPA 101 the occupant load factor is determined for different kinds of sales areas, libraries, and classrooms. The occupant load factor for sales areas varies between 2.8

m^2/person and 5.6 m^2/person. The occupant load factor for stacking areas of libraries was as high as 9.3 m^2/person and for classrooms 1.9 m^2/person. The international building code differs only with sales areas. In the international building code, only mercantile areas are specified, and the occupant load factor is determined to be 5.6 m^2/person.

For assembly and business premises the occupant load factor determined in Finnish regulation is at a conservative end of the spectrum when compared to the international standards. However, in the most crowded area, the occupant load factor is estimated to be even higher according to both standards. According to both standards, the occupant load factor in concentrated use without fixed seating can be as high as 0.65 m^2/person and in the IBC2018, standing areas are estimated to be 0.46 m^2/person. In this group, another end of the spectrum can be found when compared to the museums and galleries. According to NFPA 101 occupant load in galleries is estimated to be 9.3 m^2/person whereas in IBC2018 museums are 2.8 m^2/person.

For production and storage areas, the occupant load factor is determined in Finnish regulation to 33.3 m^2/person. In international standards as in other countries' regulations, generally, this does not match with the occupant load factors that are determined for industrial buildings. Both NFPA 101 and IBC2018 determine occupant load factor for industrial areas to 9.3 m^2/person. For different kinds of warehouses and storage areas, the occupant load factor is determined to be either 27.9 m^2/person or 46.5 m^2/person.

Table 13.: Comparison of occupant load factors from Finnish regulation and international standards

Finland	Occupant load factor (m^2/p)	Life Safety code 101	Occupant load factor (m^2/p)	IBC 2018	Occupant load factor (m^2/p)
Dwellings	10 (1 p/m^2)	Apartment buildings	18.6	Residential	18.6
Accommodation premises	10 (1 p/m^2)	Hotel and dormitories	18.6	Dormitories Residential	4.65 18.6
Institutions	10 (1 p/m^2)	Board and care Detention and correctional use Inpatient area Sleeping area Ambulatory health care	18.6 11.1 22.3 11.1 14	Inpatient area Outpatient area Sleeping area	22.2 11.1 9.3
Assembly and business, in general	2,5 (0.4 p/m^2)	Library stacking Library reading Sales area on street floor Sales area on two or more street floors Sales area on below street floor Sales area above street floor Classroom	9.3 4.6 (net) 2.8 3.7 2.8 5.6 1.9	Library stacking Library reading Mercantile Classroom	9.3(gross) 4.6(net) 5.6 1.9
Assembly and business, amusement, art, etc.	1 (1 p/m^2)	Concentrated use without fixed seating Stages Galleries Casinos	0.65 (net) 1.4 (net) 9.3 (net) 1	Assembly without fixed seats Standing spaces Stages Museum Gaming floors	0.65 (net) 0.46 (net) 1.4 (net) 2.8 (net) 1
Production and storage	33.3 (0.03 p/m^2)	General- and high-hazard industrial Special purpose industrial Storage in mercantile occupancies Storage in other occupancies Storage in storage occupancies	9.3 MP 27.9 46.5 MP	Industrial areas Agricultural buildings Warehouses Accessory storage areas, mechanical equipment room	9.3 27.9 46.5 27.9

MP=The maximum probable number of occupants present at anytime

3.5.5 Occupant load factor in shopping malls

When observing occupant load factors from the regulations of different countries or in international standards, it can be seen that occupant load factors are very rarely estimated for shopping malls. According to the Finnish regulation, shopping malls would fall under the category Assembly and business, general which means the occupant load factor would be $2.5m^2/p$, and according to Swedish BBR the occupant load is determined to be $2m^2/p$.

The international standards NFPA 101 and IBC2018 provide a more detailed way of estimating the occupant load factors in shopping malls. Figure 1 is from NFPA 101 and is used to estimate the occupant load factor in the shopping mall. According to NFPA 101, 270 shopping malls of different sizes were studied and found that an increase in the size of the shopping center will lead to a decrease in the number of occupants per square foot of cross-leasable area.

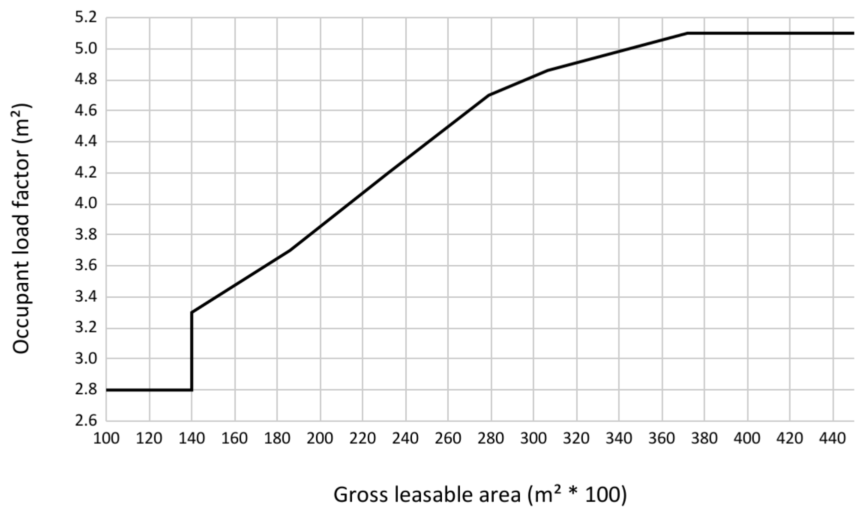

Figure 1. Occupant load factor in shopping malls according to the NFPA 101: Life Safety Code

In the IBC2018 the occupant load factor for malls is determined with the equation 5.

$$OLF = (0.00007) * (GLA) + 25 \quad \text{(Equation 5)}$$

Where

OLF = The Occupant load factor (square feet per person).

GLA = The gross leasable area

The occupant load factor must be between 30 and 50 square feet per person which means $3.34m^2$/person - $4.65m^2$/person according to international building codes. When this is compared with the NFPA 101 the occupant load factors are almost the same, since according to the NFPA Life safety code the occupant load factors in shopping malls varies between 3.3 m^2/person and 5.1 m^2/person which means that the variation range of occupant load factor is little wider when it is determined with the NFPA Life safety code.

4. METHODOLOGY

In the methodology the whole workflow of the thesis study is presented. The methodology consists of three parts, namely data collection, data analysis and evacuation simulations. In the data collection part, the methods that are used in order to collect the data are presented. The data section presents how the data is analyzed. Finally, the evacuation simulation's part presents the justification on why the evacuation simulations are needed. Those are then explained including description of the simulation model, occupant characteristics and how the number of repeated simulations runs are determined.

4.1 Data collection

In this thesis there were three research questions that needed to be answered. First is how regulation-based occupant load factors correspond with the real occupant densities measured in Finnish premises, second is how occupant load factors correspond with international standards and regulation of the other countries and lastly what is the impact of Covid19 pandemic for the occupant load. In order to answer this question data needs to be collected.

In order to carry out the comparison of occupant load factor given by Finnish regulation and the occupant densities measured from Finnish retail premises, the occupant density data needs to be collected from actual premises in Finland. In order to do this, the first objective is to define what kind of information is needed and how much. The second task is to make the contact e-mail and try to contact the facilities that could share the information for this study and lastly the data needs to be collected.

In order to compare the occupant densities from different premises and with the regulated occupant load factor the net customer area from each premise were asked along with the highest number of occupants simultaneously inside the building during the research period. In order to see if there are fluctuations in the highest occupant load, the data was asked from every day during the research period.

Since one of the questions was to find out how the occupant load has changed due to Covid-19 pandemic, the research period was decided to contain the years 2019 and 2020. According to Finnish Institute of health and welfare the first confirmed Covid19 cases were recorded in Finland in the beginning of 2020 and the first Covid restrictions and suggestion came into force on 12.3.2020 (Onnettomuustutkintakeskus, 2021). Year 2019 was chosen to represent the normal times, where the affection of Covid19 pandemic is not seen in occupant numbers and 2020 represent the pandemic conditions.

The companies were contacted by email and phone calls. In order to keep them interested in the project the companies were offered to have a short fire safety audition by KK-Palokonsultti Oy in return from the information they provided for the thesis. The privacy of the companies are respected and the companies are handled anonymously in this report. The confidentiality agreements were signed between the companies and KK-Palokonsultti Oy in order to ensure their privacy and safety of confidential information.

4.2 Data analysis

The data analysis is the part that was made after all the data is collected. The analysis was made in three parts. In the first part, which was made in a literature review, the occupant load factors determined by the Finnish fire safety regulation is compared with the national regulations of the other countries and international standards. In the second part the occupant densities from Finnish regulation are compared to the data that is collected from actual premises. In the last part the pre-covid collected data is compared with the collected data during the covid time in order to evaluate if there are differences.

In order to analyze collected data the mean value, standard deviation and maximum values of occupant densities at each premise are presented in a table. The minimum values were left out, since the Finnish National Building Code clearly states that the building must be designed for the highest possible occupant load. The premises are all shopping malls, and they will be called with the corresponding letter in order to protect the privacy of the premises. Also, the line charts are plotted on each premise where the distribution of occupant densities are compared with the year 2019 and 2020.

The comparison of the occupant load factor and actual occupant density in real buildings are made by comparing the occupant load factor of general assembly and business premises with the values that are presented in the table of each premise. In order to make the comparison the occupant density of each premise is presented in persons per square meters. The regulated occupant load factors are divided by the measured occupant densities. If the values are close to 1, it means that the occupant load factor predicts quite well the occupant loads in the buildings, however it does not leave any room for the possible change if the occupant loads would increase in a building in the future. If the values are less than one, it means that occupant load factor underestimates the occupant loads and predicts less people that there actually are in the building. Lastly, if the values are more than 1 the occupant load factor overestimates the occupant loads inside the building. The example of this ratio is presented in equation 6.

$$\frac{OLF}{OD} = \frac{0.4\ persons\ /\ m^2}{0.124\ persons\ /\ m^2} = 3.22 \quad \text{(Equation 6)}$$

OLF = Occupant load factor
OD = Measured occupant density

4.3 Evacuation Simulations

The evacuation simulations were used to investigate the effects that different occupant loads and the Covid19 pandemic had on the RSET. The other use for evacuation simulations is to visualize the effects that different occupant load or pandemic situation might have in occupant behavior. The main interests are to compare the occupant behavior if the occupant load is determined according to the regulated occupant load factor of 0.4 person/m^2 and with the actual measured occupant densities. Secondly the differences in egress are studied with the occupant loads measured before the pandemic and during the pandemic.

The egress simulation software that is used in egress simulations is Pathfinder version 2021.4. The main reason why the Pathfinder software is used is that it was available to use and was considered suitable software for the purpose. Pathfinder uses a continuous 2D triangulated model that forms the navigation mesh where occupants can move freely within its boundaries (Thunderhead Engineering, 2021). Other alternative programs with continuous modeling approach and the ability to represent physical distancing could have been used, but the availability to the Pathfinder software was the main reason to use it (Thunderhead Engineering, 2021).

4.3.1 Simulation model

The model that is used in simulations is a realistic fictitious shopping mall that is planned according to Finnish regulations. The area of the shopping mall is 14350m^2 and the shopping mall contains two floors. Each floor forms its own individual escape zone and the number, width and location of the exit doors and staircases are designed, according to Finnish National Building Code and for the occupant load that is estimated with the occupant load factor provided in the guidance document of the National Building Code. The evacuation distances are designed so that they will not exceed the distances provided in the National Building Code. The shopping mall is equipped with an automatic fire alarm system and sprinkler system. (Ympäristöministeriö, Asunto- ja rakennusosasto, 2003).

Ground floor is presented in figure 2. The ground floor is 10 000m^2 and consists of two large retail spaces. On the northern, western and southern sides of the shopping mall there are smaller retail spaces. Inside the shopping mall there are five main entrances. Four of those are located at each end of the main corridor and one of the main entrances is on the eastern wall and leads to one of the other large retail spaces. On the northern corridor there are two 1.5m wide walkways that transport people between the two floors. On the southern corridor there is a three meter wide open staircase that connects the two floors. In the northwest, northeast and southwest corners there are stair rooms that act as an escape road from the first floor. Those cannot be accessed from the ground floor, and they lead directly outside from the shopping mall.

Figure 2. Ground floor of the simulation model. Black lines represent the longest escape routes.

The first floor is presented in figure 3. The area of the second floor is 4350m^2. On the northern corridor there are business premises which are about 200m^2 except the last one in the northeast corner which is about 300m^2. Behind the business premises on the northern corridor there is a 2m wide corridor that connects to the stair rooms. This corridor provides the second escape option for the business premises. On the Southern corridor there are smaller business premises on the two sides of the corridor. From the first floor it is designed that occupants would escape to the protected staircases in the corners of the floor. Therefore, it is assumed also that the walkway on the northern corridor stops automatically in case of the fire alarm.

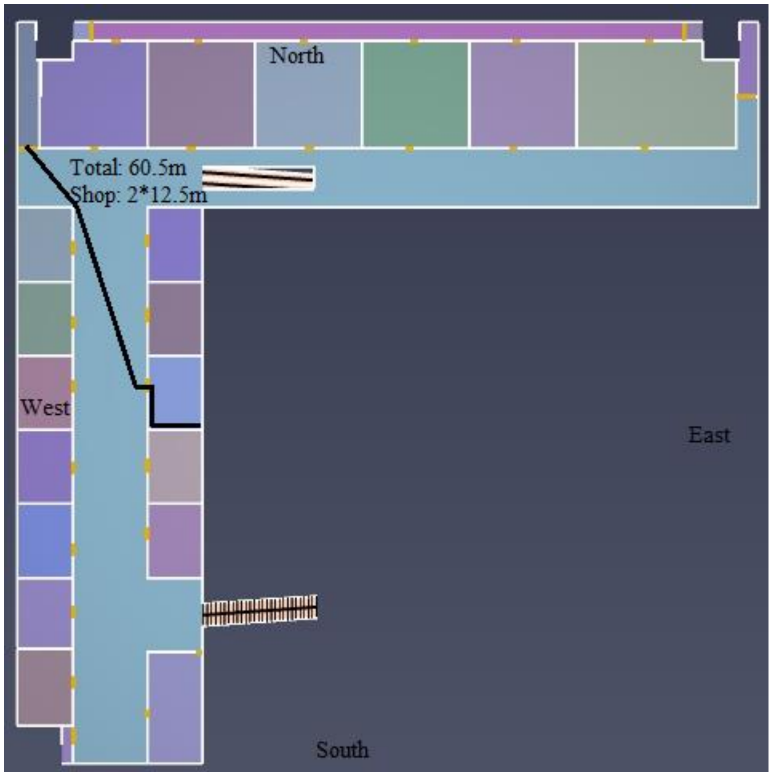

Figure 3. First floor of the simulation model. Black lines represent the longest escape routes.

The maximum travel distance in the exit zones where there is only one exit and is equipped with automatic fire alarm device and sprinkler device is 30m, in the shops where there are at least two exits the maximum travel distance is 45-60m and in other spaces the maximum travel distance is 60-70m. The lower limit is when the floor height is 3m and the higher limit is for 10m and in between values should be interpolated. The floor height in the shopping mall is 5m but the structure is open where the floors are not overlapping, so ceiling height for the ground floor is 10m. maximum travel distances:

- Ground floor shops: 60m
- Ground floor other: 70m
- First floor other: 63m
- First floor shops: 49.3m
- First floor shops with one exit: 30m

The travel distance is measured according to the shortest possible route, however inside the shops and retail areas the distance is measured along the walls, since in the shop there would be shelfs and other obstacles that occupants need to get past. The maximum travel distance on the ground floor is presented in figure 2. The maximum travel distance can be found from two large retail spaces. The travel distances from both spaces are 62m. The maximum allowed escape distance is 70 meters because the escape door is in the corridor. However, the part of the escape route that is inside the shop must not cross the distance of 60m. Since the part of the escape routes inside the shops is about 30 meters the total travel distance is acceptable.

At the first floor the maximum travel distance can be found from the small retail premises at the southern corridor (Figure 3). The maximum travel distance to the escape stair room must be less than 63 meters. However, the part of the escape route that moves inside the small retail space where there is only one exit must be less than 30 meters. Also, the part of the escape route that moves inside the small retail premise must be doubled because the Finnish 848/2017 states that if the passageway to two separate exits partly join, the length of the common part must be doubled. The total maximum travel distance at the first floor is 61m. The part that goes inside the small retail space is 9 meters and since that is a common path in the route for two separate exits this must be doubled into 18m.

According to the 848/2017 34§ the exit width is calculated from the maximum occupant load. The occupant load factor that should be used to estimate the occupant load can be found in the guidance document of the decree. Occupant load factor for general assembly and business premises is 0.4 person/m^2. Occupant loads are as follows:

- Ground floor: $10\,000\, m^2 \, * \, 0.4\, persons \, / \, m^2 = 4000\, persons$
- First floor: $4350\, m^2 * \, 0.4\, persons \, / \, m^2 \; = \; 1740\, persons$

The width of exit must be at least 1.2m and height 2.1m. If the number of occupants exceeds 120, the total minimum width is calculated by increasing the minimum width by 0,4m for each group of 60 people. This way the exit widths are calculated:

- The minimum width for ground floor: 27m
- The minimum width for the first floor: 12m

On the ground floor the small retail areas are so large that travel distances are longer than the maximum allowed distances, therefore each retail space must be equipped with a back door. The width of each back door is 1.2m and in total there are 14 backdoors on the ground floor.

Since each one of the retail stores at the ground floor is equipped with the backdoor, it would mean that the width of the main doors would be very narrow if the building would have been equipped only with the minimum required door width. The theory of affiliation predicts that in the case of emergency the occupants tend to move towards familiar people and familiar exit routes. This means that in case of an emergency people would move towards the main entrances and therefore the main entrances should be wider. In the research on *People's behavior in the central solarium area of the building* 72% of the people escaped from the main entrance (Sime. 1985.) Therefore, the width of the main doors is calculated so that about 72% (2880) of people at ground floor escape from one of the main entrances. The total exit width from the ground floor is 36.3m considering both the small back doors from each premise and the main doors.

At the first floor people are supposed to exit via protected stair rooms that are located in each corner of the floor. The minimum exit width of the first floor is 12m. There are five stair rooms with a 2.5m staircase. The total exit width on the first floor is 12.5m

4.3.2 Occupant characteristics

The occupants are divided into four different main profile categories: Adult, Children, Elderly and Wheelchair. Children are considered to be less than 15 years old, Elderly more than 65 years old and adults are from 15 to 64. The age is not determined for the people in a wheelchair. According to Statistics Finland the population distribution in Finland was distributed as follows in 2019 (Tilastokeskus, 2020):

Table 14. The age distribution in Finland in 2019 (Tilastokeskus, 2020)

-15 years	15-64 years	65- years
16%	62%	22%

However, to use more conservative assumptions, a stricter distribution is used, in order to make sure that the simulation leads to safe results. The conservatism is added by increasing the percentage of children and elderly in the simulation. Adding the percentage of children and elderly is considered to be more conservative than having a larger percentage of adults, since they are slower to walk. In addition, the percentage for the people with the wheelchair was determined according to the common practice of the company KK-Palokonsultti. In the company, the percentage of 2% is often used for wheelchairs in shopping mall buildings and it is generally accepted in design projects by the rescue authorities of Finland.

Generally, it is assumed that people do not need assistance to escape the building. However, since on the first floor the escape is designed through the stairs, the people with the wheelchair need assistance on the first floor. Since the only way for people with the wheelchair to move independently between the ground floor and the first floor is through the walkway, it is decided that people with wheelchairs need assistance in evacuation to escape from the first floor. Two alternative profiles were made based on the profile "adult and "wheelchair." The "assist" profile is based on the profile "adult" and "assisted" is based on a wheelchair. When the simulation starts and occupants start to escape the building, people with the profile assist first go to the people that need assistance and assist them to escape the building. In the simulation two people are needed to help one person with the wheelchair to escape. The people who are assisting the people with the wheelchair are assumed to be people who came to the mall along with the people with the wheelchair.

In table 15 the basic input detail is presented. The table presents the distribution of the main occupant profiles, walking speeds, shoulder widths, pre-movement times and heights of the different occupant profiles. By default, Pathfinder uses a cylindrical body shape. The diameter of the cylinder is considered the shoulder width. The values for walking speed and shoulder width for adults, elderly and children are taken from FDS+Evac user manual (Korhonen, 2018). However, FDS+Evac approximated the body shape of the occupants to be an elliptical combination of three overlapping circles as seen in figure 4 instead of cylindrical as in Pathfinder. The shoulder width is approximated by multiplying the value Rd by 2 in order to get the diameter of the circle. The movement speeds and widths for wheelchairs were not defined in FDS+Evac User Guide, therefore the data for people with the wheelchair were searched and found from the research Fire and disabled people in buildings. The pre-movement time means the time from the alarm to the beginning of the movement. Pre-movement time is considered to consist of two phases, recognition phase and response phase. In determining the pre-movement time the research, *The Variation in Pre-movement time in Building* was used. Similar pre-movement time was suggested for all behavior groups, because the research that was used specified the pre-movement times for each building type but not for different types of occupant profiles. Therefore, the pre-movement time for department stores was used, and it was assumed that the values contain all different age groups. (Forssberg et al., 2019). In the evacuation scenarios it was assumed that in the beginning of the scenario, an automatic alarm system has already detected the fire and given the alarm. Therefore, the detection time or notification time is not included to the RSET in this study. The required safe egress time (RSET) consist of pre-movement time and the evacuation time in this study.

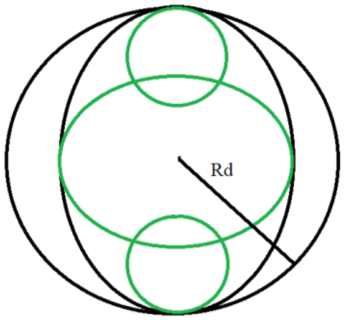

Figure 4. How the occupant shape and shoulder width is determined in FDS Evac (Korhonen, 2018).

Table 15. Basic input details for the Pathfinder simulations.

Profile	Adult	Child	Elderly	Wheelchair
Distribution:	50%	23%	25%	2%
Speed (m/s):	1.25±0.30	0.90±0.30	0.80±0.30	0.72 (0.44-1.22)
Shoulder width (m)	0.51±0.7	0.42±0.3	0.50±0.04	100cm
Pre-movement (s)	35.9/(5-111)/17.7 Mean/(min-max)/SD	35.9/(5-111)/17.7	35.9/(5-111)/17.7	35.9/(5-111)/17.7

Speed and shoulder width of adults, children and elderly: (Korhonen, 2018)
Speed of wheelchair: (Shields & Fire Research Station, 1993)
Width of wheelchair: (Shields & Fire Research Station, 1993)
Pre-movement time: (Forssberg et al., 2019)

4.3.3 Simulation scenarios

In order to determine the simulation scenarios, the variables for the simulations must be determined. Since the goal of the simulations were to illustrate the differences in building evacuation with occupant load determined with the regulated occupant load factors or with measured occupant densities before and during the pandemic, the occupant density will be chosen to be the first variable. The occupant loads will be determined with the occupant load factor given by Finnish regulation for the general assembly and business premises and with the mean and maximum occupant densities from the year 2019 and 2020 after the 12th of March.

Table 16. Summary of different route choice scenarios and their assumptions

Route choice:	Assumptions
Locally quickest path	Uses the default algorithm of Pathfinder It is assumed that the occupant knows about the doors and queues and uses this information to decide the fastest route.
Go to closest	In the fire scenario, it is assumed that people escape using only the closest exits. From the first floor people are assumed only to use protected stair rooms.
70/30	According to theory of affiliation in case of fire, most people move towards familiar exits and people. Therefore 70% use main exits and 30% any exit.
Go to main	It is assumed that people are using only main exits.

The second variable is the route choice. There are four different route choice scenarios that will be modeled that are presented in table 16. Firstly, the evacuation will be modeled with occupants choosing the door leading to the quickest time (based on Pathfinder default locally quickest algorithm)(Thunderhead Engineering, 2021a). The closest possible route may not be the fastest or the best route for the particular occupant due to crowds or other obstacles on the way to the exit. Pathfinder uses the locally quickest method in path planning. In this method it is assumed that the occupants know about all the doors that are in the room where they are and about the distances to those doors. In addition, the occupants know about the crowds in front of the doors in the room where they are. The locally quickest method then uses this information to determine the route to the door which leads to the fastest egress from the building. (Thunderhead Engineering, 2021a). This route choice scenario is called “Locally quickest path” in this report.

The second route choice scenario that is modeled, is where all the occupants escape as it is designed in the evacuation plan. On the ground floor, route choice is set to the “Locally quickest path” for all the occupants. However, on the first floor some of the people with this route choice would go back to the ground floor through the staircase or walkway and evacuate from there. This is not wanted, since the walkway and stairs are in open space and therefore in a fire scenario people could be exposed to the smoke. The stair rooms in the corners of the first floor are protected from smoke and are designed to be used by all of the occupants on the first floor. The route choice on the first floor is set so that people may choose between the stair rooms in the corners of the building. This route choice option is called “Go to closest” since in this scenario it is assumed that occupants exit as designed and use only the closest exits.

Even though the evacuation is designed so that people would use the closest possible exits it is common that people will use the main entrances where they came from. This is called the theory of affiliation. In the third route choice scenario the theory of affiliation is taken into account, and it is assumed that most of the occupants use the main exits, and a smaller percentage may use any exits. In the earlier research where evacuation has been researched from the central solarium area, it was noted that 72% used the main entrance. (Sime, 1983, 1985). Therefore, in this scenario 70% of the people from the ground floor and from the first floor are assumed to use main entrances.

The rest from the ground floor uses any exits and from the first floor occupants use stair rooms. This route choice scenario is referenced as “70/30” in this report.

In the last route choice scenario, people are assumed to use only the main entrances. The goal of this scenario is to illustrate the highest possible escape time, in the scenario if all the occupants decide to egress from the main entrance. This route choice scenario is referenced as “Go to main” in this report.

The last variable is related to the physical distancing due to the pandemic. The suggestion for safe distance between occupants has changed many times during the Covid19 pandemic. On the informational video that is published by the Institute of Finnish Health and Welfare on 30.11.2020 the safe distance is instructed to be at least 1m (Terveyden ja hyvinvoinnin laitos, 2020). However later the safe distance is increased to 2m due to new mutations of Covid19 virus (Terveyden ja hyvinvoinninlaitos, 2021). According to the results from a study about perceived effectiveness, restrictiveness and compliance of different Covid-19 restrictions, the compliance of Covid-19 restrictions were researched in 11 European countries. The compliance of physical distancing was on average 73% and in Finland Compliance of physical distancing was 81%. (Georgieva et al., 2021) However the results of this study were collected by asking people to fill the survey. This means that in normal circumstances 81% tries to comply with physical distancing. However, this does not take into account, if the people would be compliant to keep physical distance even in case of fire evacuation. In the case of fire people are advised to leave the building as fast as possible.

In the research “The Impact of Physical Distancing on the Evacuation of Crowds” the influence of physical distancing was studied. In the first scenario people were asked to keep a physical distance of 1 meter towards each other and in scenario 2 the physical distance of 2 meters towards each other. It was observed that when the goal distance was 1 meter people were able to keep on average 1.24 meter physical distance but when the goal distance was set to 2 meter the average physical distance was 1.82 meter (Ronchi et al., 2021). According to this, it looks like even if people want to comply with the physical distancing goal, when the physical distance goal is increased it becomes harder for people to keep the distance towards other people.

If the people are physical distancing during the evacuation, it would increase the evacuation time, which may lead to fatalities if the threat of fire is direct (Butail & Porfiri, 2021). In the early part of fire, the first cue from the fire for the occupants in the building is often the sound of a fire alarm. If the building is large or the fire is in the incipient stage people become uncertain about the situation and might ignore the fire and think it would probably be a false alarm, since they cannot see any other signs of fire. After the occupants are able to see more cues, like smoke or flames, they start to react faster to the fire, since they realize the alarm is serious. This theory is called Behavioral sequence model and it was first proposed by Canter, Breaux and Sime (Canter et al., 1980; Nilsson, 2014). Since shopping malls tend to be large buildings, some of the people might not be able to see or hear any other cues than the sound of the fire alarm. Therefore, it is assumed that a small number of the occupants do not feel the direct danger from the fire and decide to keep physical distancing during evacuation. The small number of people who are physical distancing is assumed to be 5% of the occupants and they are assumed to keep 2m physical distance from the other occupants. The percentage physical distancing was estimated to be quite small, because of three reasons. Firstly, even if there would be suggestion to physical distance it was observed that only 81% of the people are physical distancing in the first place (Georgieva et al., 2021). Secondly even if there are people trying to keep physical distance of 2 m on average the distance is shorter (Ronchi et al., 2021). Lastly, the previous studies considered normal situation during the pandemic. According to the behavioral sequence model people will react more seriously to the fire, when they see smoke and flame. Even if some people from the building are not able to see the fire some others are who might be close to the fire during the ignition. The occupants who were able to see more cues like smoke and flames takes the alarm seriously and therefore escape the building as fast as they can and therefore are not physical distancing. The simulation scenarios that are simulated are presented in the tables 17, 18 and 19.

Table 17. Simulation scenarios where the regulated occupant load factor is used

Scenario	Occupant density (persons/m^2)	Route choice	Physical distancing
1	0.4	Locally quickest path	Yes
2	0.4	Go to closest	Yes
3	0.4	70/30	Yes
4	0.4	Go to main	Yes
5	0.4	Locally quickest path	No
6	0.4	Go to closest	No
7	0.4	70/30	No
8	0.4	Go to main	No

Table 18. Simulation scenarios where the maximum measured occupant density and mean occupant density in 2019 are used.

Scenario	Occupant density (person/m^2)	Route choice	Physical distancing
9	Maximum (2019)	Locally quickest path	No
10	Maximum (2019)	Go to closest	No
11	Maximum (2019)	70/30	No
12	Maximum (2019)	Go to main	No
13	Maximum (2019)	Locally quickest path	Yes
14	Maximum (2019)	Go to closest	Yes
15	Maximum (2019)	70/30	Yes
16	Maximum (2019)	Go to main	Yes
17	Mean (2019)	Locally quickest path	No
18	Mean (2019)	Go to closest	No
19	Mean (2019)	70/30	No
20	Mean (2019)	Go to main	No
21	Mean (2019)	Locally quickest path	Yes
22	Mean (2019)	Go to closest	Yes
23	Mean (2019)	70/30	Yes
24	Mean (2019)	Go to main	Yes

Table 19. Simulation scenarios where the maximum measured occupant density and mean occupant density during the pandemic are used.

Scenario	Occupant density (person/m^2)	Route choice	Physical distancing
25	Maximum (Covid)	Locally quickest path	Yes
26	Maximum (Covid)	Go to closest	Yes
27	Maximum (Covid)	70/30	Yes
28	Maximum (Covid)	Go to main	Yes
29	Maximum (Covid)	Locally quickest path	No
30	Maximum (Covid)	Go to closest	No
31	Maximum (Covid)	70/30	No
32	Maximum (Covid)	Go to main	No
33	Mean (Covid)	Locally quickest path	Yes
34	Mean (Covid)	Go to closest	Yes
35	Mean (Covid)	70/30	Yes
36	Mean (Covid)	Go to main	Yes
37	Mean (Covid)	Locally quickest path	No
38	Mean (Covid)	Go to closest	No
39	Mean (Covid)	70/30	No
40	Mean (Covid)	Go to main	No

In addition, one more set of simulation was made. The purpose of this simulation was to find out how much the door width can be decreased so that the RSET with occupant density of 0.125 person/m^2 matches the RSET that is find with the full door width and with the occupant load estimated with the occupant load factor. The second goal is to found the threshold value for the maximum occupant load determined with the measured maximum occupant density, so that queues are begin to form and the door width starts to restrict the flow, in this specific simulation model. This was investigated by running the simulations of each route choice scenario with the occupant density of 0.125 person/m^2 and no physical distancing. With each run the door width is decreased. The door width is decreased evenly from different sides of the building and the exit distances are tried to keep as short as possible. However, when the evacuation doors are removed in order to decrease the total door width the evacuation distances might exceed the limits provided by the Finnish legislation. The total door width that are used with the route choice scenarios where people can use other doors alongside with the main doors is 36.3 meters for the ground floor and 12.5 meters for the first floor and the total door width for the scenario where people are using only the main door in evacuation is the total width of the main doors which is 19.5 meters. The goal is to find the door width that leads to the equal RSET time as with the regulated occupant load factor of 0.4 persons / m^2.

The first step is to run draft runs with decreased door width to get approximated RSET time. When the door width is decreasing the RSET times starts to get longer and it can be found out when the RSET times get close to the equal with the RSET time that is simulated with the regulated occupant load factor and full total door width.

The second step of this study is to verify that the approximated RSET time really equals the RSET time that was obtained with the regulated occupant load factor by making the convergence study and seeing that the values converge close to the goal value.

4.3.4 Number of repeated simulation runs

During the evacuation, people make decisions on how to act. It has been researched earlier that there are multiple factors that affect these decisions. These kinds of factors are for example a person's past experiences, environmental conditions, and social influence (Kinateder at al., 2015; Kuligowski, 2016). This explains why human behavior and route choice decisions may vary significantly during evacuation. Since the factors related to human behavior cannot be specified for each individual occupant separately, the variation in human behavior is simulated by determining distributions for occupant characteristics like pre-movement time and movement speed. These variable factors are determined randomly within the limits given in table 15 for each occupant and the occupants are placed randomly to the simulation model. The issue is, one simulation represents only one specific case and the total evacuation times might change drastically if the simulation is repeated with the randomly generated occupant characteristics and occupant positions, this phenomenon is called behavioral uncertainty (Ronchi at al., 2014). In order to decrease the uncertainty caused by the variance in human behavior and human positions the simulations need to be run multiple times to see the variation in the evacuation times. The challenge is to determine the number of repeated simulation runs that are needed. (Smedberg at al., 2021.)

The number of repeated simulation runs are previously categorized in four different categories (Kinsey, 2016):

1. Brute force: All possible permutation of the stochastic variables are simulated and therefore the complete range of results is obtained.
2. Fixed number: A fixed number of repeated simulations is set to represent all potential outcomes. According to IMO guidelines 500 repeats is recommended (MSC, 2016).
3. Qualitative visual assessment: Visually assessing the results between the runs and deciding if more runs are needed.
4. Dynamic assessment of variance in output variables: Assessing the results of the simulation runs and deciding if the convergence requirement has been met.

In this study the number of repeated simulations is determined by assessing the results of repeated simulations and the convergence of the consecutive simulations. The convergence is assessed by investigating the consecutive average of total evacuation times ($\underline{TET_i}$). The convergence is calculated with the equation 7:

$$TET_{conv\ i} = \left| \frac{\underline{TET_i} - \underline{TET_{i-1}}}{\underline{TET_i}} \right| \quad \text{(Equation 7)}$$

Where $TET_{conv\ i}$ is the convergence percentage of the consecutive average of the total evacuation times (Lovreglio at al., 2014). When the percentage is less than 5% in five consecutive runs the simulation values are considered to converged enough and no more repeated simulation runs are needed.

4.3.5 Hand calculation

Since the evacuation is studied only with the simulations since there are no resources to do full scale egress research with different occupant loads, the egress is also studied with the quick hand calculations to show if the results show similar results as the simulations to bring extra justification for the simulations results.

In the hand calculations the RSET is determined similarly as in simulations and therefore detection time and notification time is assumed to be 0s, since the simulation scenario starts from the alarm. In the calculations highest possible pre-movement time is assumed and it is assumed that people are dividing evenly within the specific door type. Since the occupant placing is varying in the simulation's movement time is not included to the calculations and the approximated RSET time is calculated according to the most restrictive egress component, which is decided based on the Pathfinder simulations. Lastly the maximum specific flow of 1.3 persons/s/m and speed is 1.19 m/s is assumed (Gwynne &Rosenbaum, 2016). The calculations are performed according to the methodology presented in SFPE handbook by Qwynne & Rosenbaum (Gwynne &Rosenbaum, 2016).

5. RESULTS

In this part, the results of the thesis are presented. The first part of the results deals with the collected data. From the collected data the real maximum occupant loads from real premises were received and they were compared with the occupant load factor. Secondly the variation in occupant load before and after the Covid19 pandemic is analyzed. In the second part, the results of the evacuation simulations are evaluated. The main interests related to how variating the occupant load affects to the evacuation and what is the impact of physical distancing to the evacuation.

5.1 Collected data analysis

The data was inquired from 23 different Finnish retail business actors. Nineteen actors are shopping malls and four are department store branches that own multiple premises around Finland. The data was received from 6 shopping malls around Finland. The data that was asked was the highest number of occupants that had been inside the building simultaneously for every day during the research period and the gross occupant area. From the malls A, B, C and D the highest occupant loads of the day was given from every day during the research period and from E and F the highest occupant loads from every week was given. This is why the mall E and F will be left out from the comparisons of the mean values and standard deviation, because the amount of data from this premise is smaller than from other premises and this would distort the results. When the maximum values are compared, all malls are used.

In the table 20 mean value, standard deviation and maximum and minimum value of occupant densities are presented in persons/m^2 for all premises. The maximum values are interesting, because Finnish national building code states that when the total door width of the building is determined the maximum number of occupants should be used. However, if the occupant load is not known the occupant load factors can be used. Mean occupant density, standard deviation and the minimum occupant density values were presented in the table so that variation of occupant density can be observed. The values are presented in the form of occupant density, so that it can be compared with the occupant load factor.

The results are presented before the pandemic and during the pandemic. Before the pandemic is the time before the 12.3.2020 since after this date the Finnish government first Covid restrictions and suggestions were announced by the Finnish government. Therefore, this is considered to be the beginning of the pandemic in Finland and the occupant loads after the date represents occupant loads during pandemic. The maximum value of occupant density is presented in table 20 to illustrate the actual worst-case scenario that has been measured from Finnish premises during the research period.

The maximum value of occupant density before the pandemic was measured from mall E, where occupant density was 0.124 persons/m^2. Interestingly the highest occupant density of mall B was measured during the pandemic. The highest occupant density during the pandemic was measured in mall B and it was 0.112 persons/m^2. In the earlier research that was made to get input data for the shopping mall at Leppävaara, the maximum occupant densities were measured from three mall premises around Helsinki metropolitan area. The measured values were 0.111 persons/m^2, 0.093

persons/m^2 and 0.082 persons/m^2 which are close to the sizes that was measured for this research (Holopainen & Hassinen, 2002).

Table 20. Measured occupant density values from each mall

	Before the pandemic (1.1.2019-12.3.2020)				Pandemic (12.3.2020-31.12.2020			
Mall	Mean (person/m^2)	SD	Max (person/m^2)	Min (person/m^2)	Mean (person/m^2)	SD	Max (person/m^2)	Min (person/m^2)
A	0.014	0.026	0.048	0.002	0.009	0.011	0.031	0.001
B	0.063	0.217	0.096	0.014	0.042	0.103	0.112	0.010
C	0.020	0.023	0.078	0.001	0.009	0.005	0.028	0.000
D	0.025	0.030	0.072	0.002	0.015	0.016	0.052	0.001
E*	0.082	0.417	0.123	0.049	0.042	0.053	0.102	0.010
F*	0.065	0.435	0.098	0.050	0.042	0.111	0.062	0.020

* Highest occupant density of the week

The distributions of occupant density in different shopping malls are presented in the figures 5-7. In figures 5 and 6 the occupant densities are presented from the malls where the daily maximum occupant density is measured and in figure 7 the malls where the weekly maximum occupant density is measured. The blue line represents the year 2019 and orange 2020. On the y-axis there are occupant density. In the x axis there is time, which is presented in a number of days or weeks.

The similar trends that can be observed from all premises is that around the day 170 there is a huge decrease in the graphs which means that the occupant load in the malls have been very low on that specific time. Around the time of the decrease in the graphs there is the Finnish midsummer festival, which is the reason that most of the stores are closed, and opening times might be limited and therefore the occupant load is very low. Similar decreases can be noted in the end of the year around the day 360, which is about the time of Christmas. The common trend that also needs to be observed from the figures is a decrease at around the day 80 or in week 12 of 2020. This decrease happens to be around the same time when the first Covid restrictions and suggestions came into force in Finland and people started to do physical distancing and avoid physical contacts. This means that after the Covid restrictions and suggestions came into force occupant densities in all the shopping malls first decreased and after some time the occupant densities started to increase slowly close to the values before the pandemic.

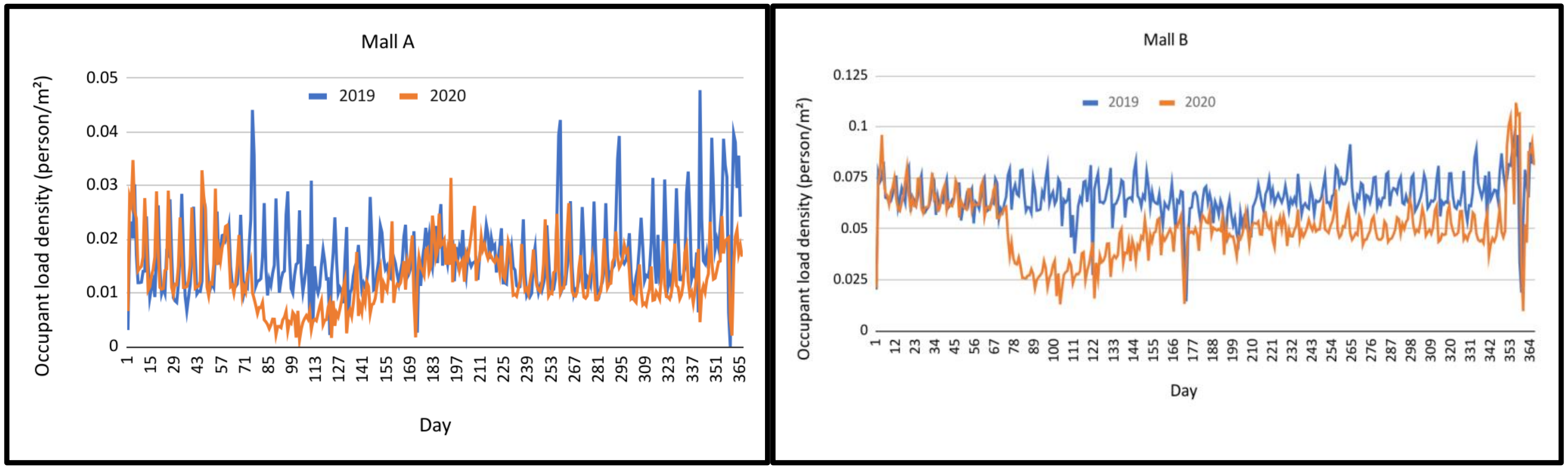

Figure 5. Distribution of daily maximum occupant density in mall A and B

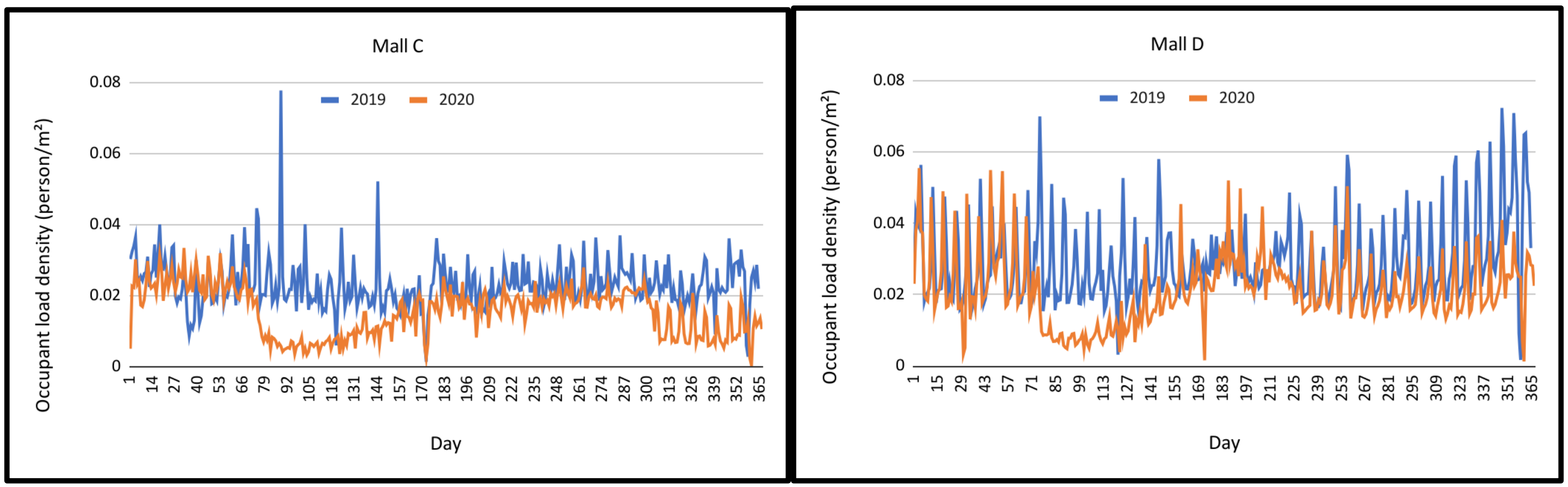

Figure 6. Distribution of daily maximum occupant density in mall C and D

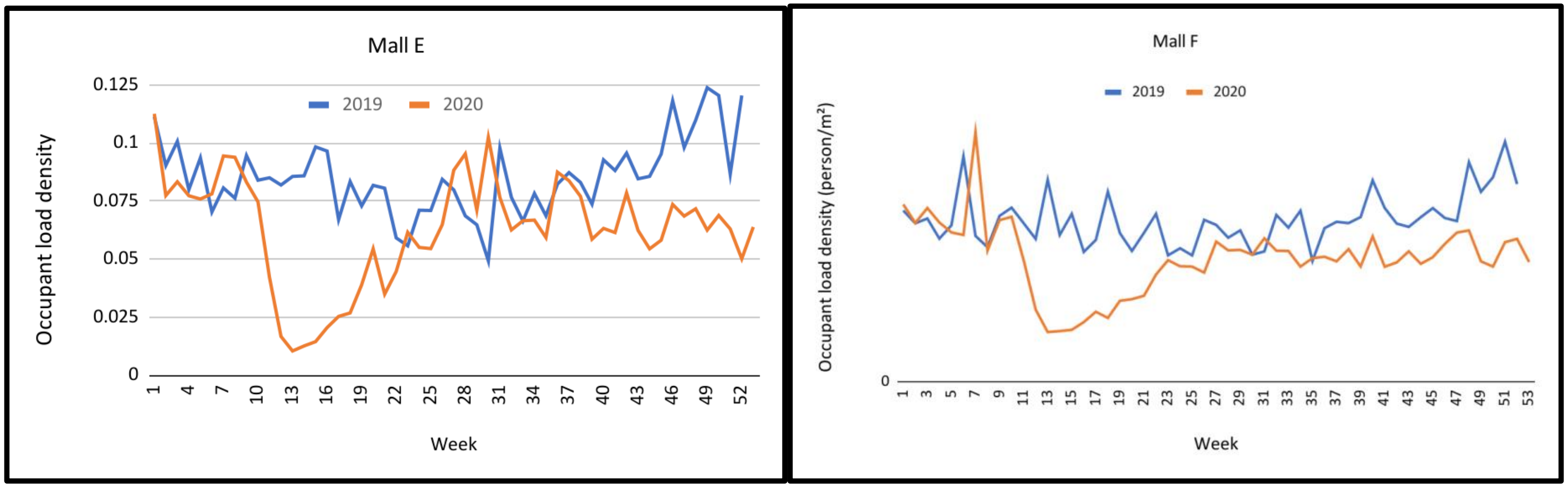

Figure 7. Distribution of weekly maximum occupant density in mall E and F

5.1.1 Finnish regulation vs collected data

In table 21 the occupant load factor of general assembly and business premises from the guidance document of 848/2017 is compared with the measured maximum occupant densities from different malls. The number in the last column illustrates the ratio of measured occupant density and the regulated occupant load factor. The occupant load factor for general assembly and business premises is 0.4 person/m^2. The measured occupant loads vary between the value of 0.125 person/m^2 from premise E to 0.048 person/m^2 from mall A.

In all six premises if the occupant density is estimated with the occupant load factor, it would lead into overestimated occupant loads. The largest overestimation is in mall A, where the maximum occupant density was lowest. In mall A the ratio of occupant load factor 8.4. The ratio is the smallest in the premise E, which means that the overestimation is the smallest as well. The ratio in mall E is 3.2 which means that the estimated occupant loads when the regulated occupant load factor is used are 3.2 times higher than the actual occupant load. On average the ratio between the occupant load factor and the measured maximum occupant load was 5.1.

Table 21. The ratio of the Maximum measured occupant load factor and occupant density

Occupant load factor (848/2017) (person/m^2)	Mall	Measured maximum occupant density (person/m^2)	Occupant load factor / Measured occupant density
0.4	A	0.048	8.3
0.4	B	0.096	4.2
0.4	C	0.078	5.1
0.4	D	0.072	5.6
0.4	E	0.123	3.2
0.4	F	0.098	4.1
		Average ratio:	5.1

5.1.2 Pre-covid collected data vs. collected data during covid

The change in mean values of occupant densities before and during covid is presented in a table 22. The occupant densities in table 22 are presented in area per person which means higher number corresponds with lower number of people. When comparing the change in mean values of occupant densities before the pandemic and during the pandemic the mall A, B, C, and D are used. The mall

E and F are left out from the comparison, since the occupant data from those premises is only collected once per week instead of once per day and therefore, cannot be compared with the other four premises.

When the mean values of occupant densities are compared before and during covid it can be noted, that in each premise the mean value of occupant density is decreased. The occupant densities are decreased from 50% to 122% from the pre-covid levels depending on the premise and on average the mean value of occupant densities has decreased 74% from the pre-covid levels.

Table 22. The change of mean occupant density before and during the pandemic in person/m^2

Mall	Mean (Pre-covid) (person/m^2)	Mean (Covid) (person/m^2)	Change of mean (%)
A	0.014	0.009	56 %
B	0.063	0.042	50 %
C	0.020	0.009	122 %
D	0.025	0.015	67 %
Average change of mean(A-D) (%):	74%		

However, one mean value does not give a very good image about the average occupant densities during the pandemic, because the occupant loads are fluctuating constantly. In the figures 8-10 the average occupant densities are presented in two months periods. In the blue column the mean occupant density for 2019 is presented and in the orange column the mean for the 2020. From these figures it can be observed that the size of the blue columns does not change a lot, which means the occupant density stays more or less the same during the whole year and the value does not fluctuate that much. When observing the orange column, it can be seen that in 2020, there has been a lot more fluctuation in occupant density. The value of occupant density in January and February are very close to the values that were measured in 2019. However, at this point of the year the covid19 restrictions have not come into force in Finland. In all premises the occupant density decreases a lot in March and April. On the 12th of March Finnish government announced the first covid19 suggestions and restrictions. After April the occupant density started to increase towards the occupant density levels of 2019. In all premises the occupant density remained little bit lower at the end of 2020 than in 2019 except in premise C, where occupant density decreased significantly in November and December. The reason for this significant drop in the occupant density is unknown.

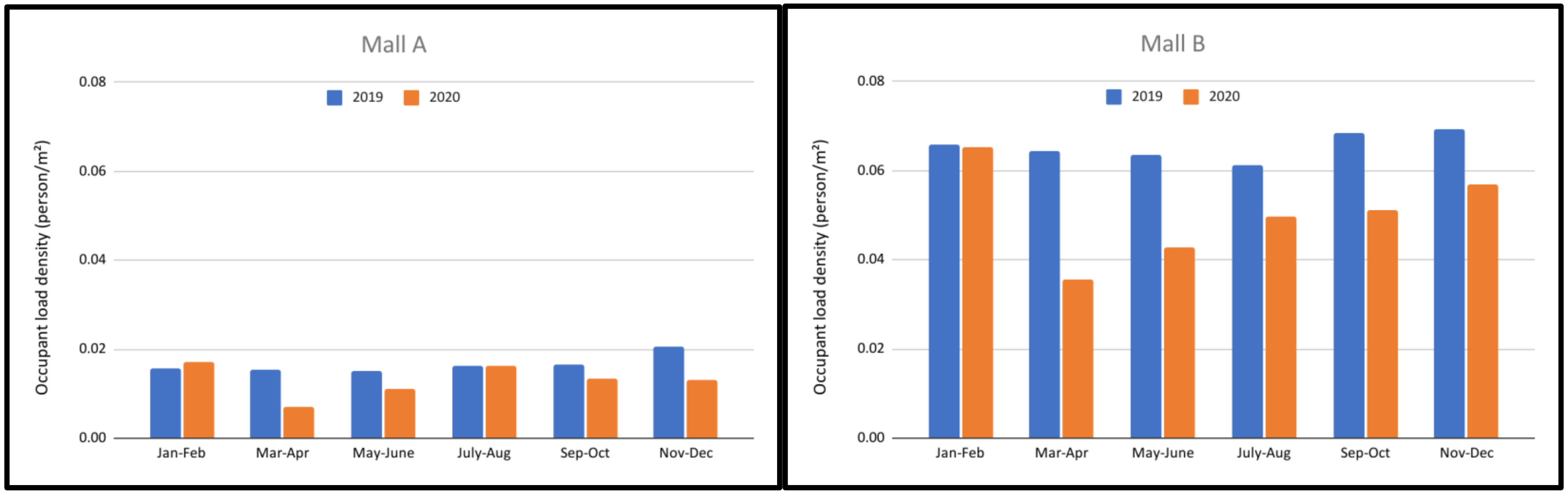

Figure 8 The average occupant denstiy in two months period from the malls A and B

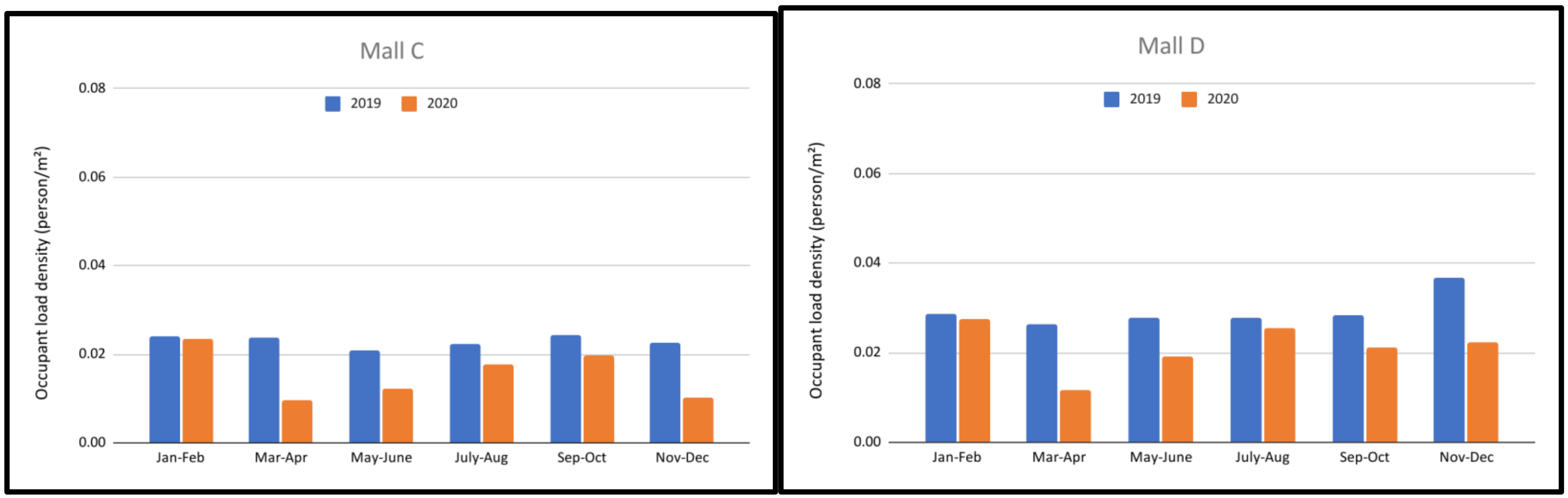

Figure 9. The average occupant density in two months period from the malls C and D

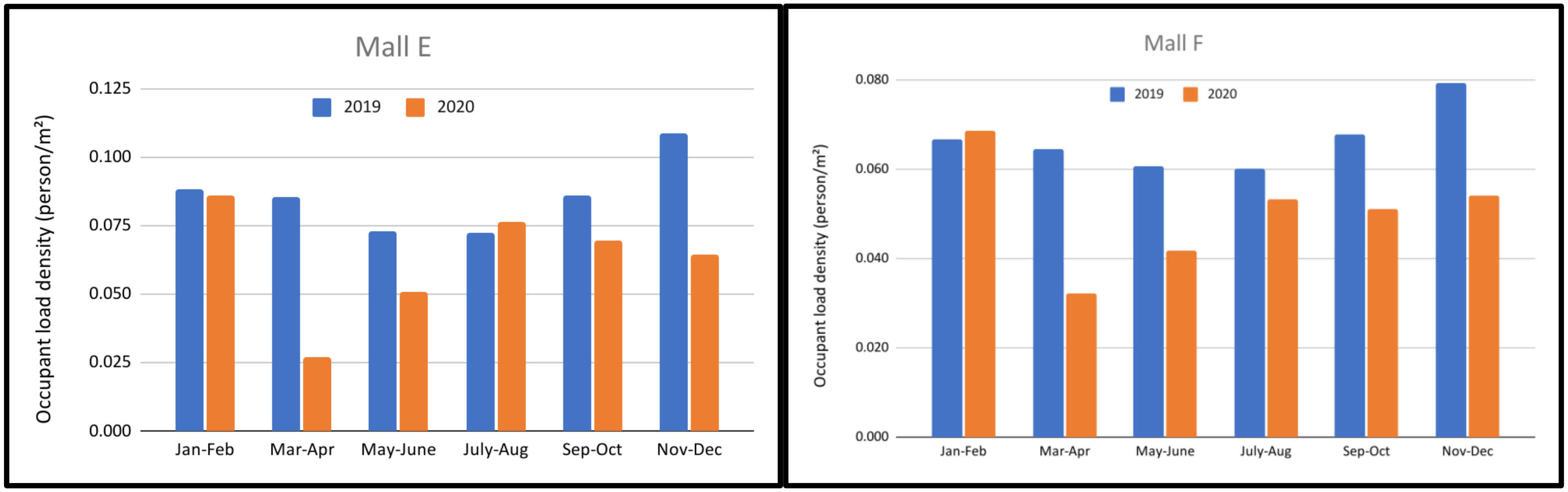

Figure 10. The average occupant density in two months period from the malls E and F

In table 23 the changes in the maximum occupant densities are compared before and during covid. It can be noted that the maximum occupant density has decreased in all premises except in mall B, where the occupant density has increased for 14%. In general, the average change of the maximum occupant density is smaller than the average change of the mean occupant density. The variation range of maximum values is higher, since it varies from the increasing of 14% to the decreasing of 179%.

Table 23. Change of maximum occupant density before and after pandemic in person/m²

Mall	Max (Pre-covid) (person/m²)	Max (Covid) (person/m²)	Change of max
A	0.048	0.031	55%
B	0.096	0.112	+14%
C	0.078	0.028	179%
D	0.072	0.052	38%
E*	0.123	0.102	21%
F*	0.098	0.062	58%
		Average change of max	56%

5.2 Simulation analysis

In this part of the report, the results from evacuation simulations are analyzed. Simulations were made by varying three different variables, which were occupant load, route choice and if there are occupants physical distancing due to covid19 pandemic. The occupant load values that were used were received from collected data analysis and six different occupant loads were used and they are presented in table 24.

In simulation analysis it is considered that RSET starts in the begin of the simulations, which means the detection time and notification times are not included to the RSET. The RSET end when the simulation ends which means the time when all the occupants are out of the building. This definition of RSET is used also with the hand calculations that are made to back up the simulation results.

Table 24. Occupant density values that was used in Pathfinder simulations and number of occupants in ground floor and first floor

Scenario	Occupant density (person/m^2)	Occupant load in ground floor	Occupant load in first floor
Finnish regulation	0.4	4000	1740
2019 maximum	0.125	1250	544
2019 average*	0.0227	227	99
Covid maximum	0.112	1124	488
Covid average*	0.013	130	56

* Average values were calculated by taking the average from the average occupant densities from premises A-D.

The simulations were repeated multiple times. The number of repeated simulations were determined by convergence study, where convergence of the results was investigated by assessing the consecutive average of the total evacuation times. The results of each simulation run and convergence study is presented in Annex 2. The results are considered to be converged, if the consecutive average variates less than 5% in five consecutive runs.

The results of different simulation scenarios are presented in table 25. In the table on the left side are presented all the scenarios without considering physical distancing and on the right side the results are presented with physical distancing. Different background colors represent different occupant loads where yellow represents maximum occupant load before the pandemic and red represents maximum occupant load during the pandemic. The orange represents mean occupant load before the pandemic and gray represents mean occupant load during the pandemic and the green represents the regulated occupant load factor. The values labeled with a * represents theoretical values. For example, the occupant density of 0.125 represents the maximum occupant load before the pandemic and therefore the physical distancing does not apply to the results. The 0.125* represents the theoretical situation where the physical distancing is applied to the scenario in order to reveal how much the physical distancing would affect the evacuation time with the specific occupant load. Similarly, the occupant density factor 0.112 represents the maximum value during the pandemic so the physical distancing effect on the results, so 0.112* represents the theoretical value if the physical distancing would not affect the results. The average RSET is calculated by taking the average of each simulation run for the specific case.

Table 25. Simulation results of different simulation scenarios.

Occupant density (person/m²)	Behavior	Physical distancing	Average RSET (s)	Occupant density (person/m²)	Behavior	Physical distancing	Average RSET (s)
0.125	Locally quickest path	No	204	0.125	Locally quickest path	Yes	209
0.125	70/30	No	282	0.125	70/30	Yes	287
0.125	Go to closest	No	216	0.125	Go to closest	Yes	214
0.125	Go to main	No	347	0.125	Go to main	Yes	370
0.112	Locally quickest path	No	196	0.112	Locally quickest path	Yes	205
0.112	70/30	No	262	0.112	70/30	Yes	275
0.112	Go to closest	No	195	0.112	Go to closest	Yes	213
0.112	Go to main	No	343	0.112	Go to main	Yes	351
0.0227	Locally quickest path	No	173	0.0227	Locally quickest path	Yes	159
0.0227	70/30	No	225	0.0227	70/30	Yes	226
0.0227	Go to closest	No	177	0.0227	Go to closest	Yes	179
0.0227	Go to main	No	248	0.0227	Go to main	Yes	251
0.013	Locally quickest path	No	178	0.013	Locally quickest path	Yes	160
0.013	70/30	No	200	0.013	70/30	Yes	224
0.013	Go to closest	No	164	0.013	Go to closest	Yes	183
0.013	Go to main	No	243	0.013	Go to main	Yes	262
0.4	Locally quickest path	No	319	0.4	Locally quickest path	Yes	363
0.4	70/30	No	488	0.4	70/30	Yes	549
0.4	Go to closest	No	435	0.4	Go to closest	Yes	494
0.4	Go to main	No	704	0.4	Go to main	Yes	812

5.2.1 Impact of different occupant loads on evacuation

The effect of occupant loads to the evacuation can be observed from table 25. When the other variables are fixed, and the occupant density variates, it can be observed that with lower occupant density the evacuation times are faster than with higher occupant densities. This means that when the occupant load is higher, the evacuation takes more time.

In table 26 the evacuation times with the maximum measured occupant density and mean measured occupant density is compared to the evacuation times with the regulation based occupant load factor. Since the regulation based occupant load factor is higher, the evacuation times with regulation based values are higher. In the comparison where the evacuation times are compared with the maximum measured occupant density and regulated occupant load factor, it was noted that evacuation times are 36% to 51% higher with the occupant loads estimated with the occupant load factor. The difference is smallest with the case where evacuation is not restricted, and occupants may choose any exit. The difference was highest in the scenario where only the main doors were used. When the mean measured occupant density is compared with the regulated occupant load factor the difference is even higher. The lowest difference between the scenarios was measured from the scenario where occupants may choose any exit and the results were 46% higher with the regulated occupant density. The highest difference was again with the scenario where only main exits were used and the difference was 65%.

Table 26. On the left side there are comparison of RSET with the maximum measured occupant density and occupant load factor and on the right side comparison of mean measured occupant load density and occupant load factor

2019						
	0.125 person/m^2	0.4 person/m^2	Difference (%)	0.0227 person/m^2	0.4 person/m^2	Difference (%)
Go to any	204 s	319 s	36%	173 s	319 s	46%
70/30	282 s	488 s	42%	225 s	488 s	54%
Go to closest	216 s	435 s	50%	177 s	435 s	59%
Go to main	347 s	704 s	51%	248 s	704 s	65%

The reason for the differences was studied from the Pathfinder visualizations. From the figure 11 it can be observed that with the regulation-based occupant load factor, which was the highest, the most queues were formed. The queues restrict the natural flow through the doors and staircases and therefore slows down the evacuation. When the simulations were simulated with the measured mean occupant density the occupants did not form any queues and they were able to leave the building faster. The queues were also formed more easily if the number of evacuation routes were restricted. In scenarios where people were able to choose any exit the people separated more evenly to all the exits, since the queues were not formed, and evacuation was faster. When the exit choices were limited, more queues were formed, and evacuation time was longer. The longest evacuation time was measured when people were only able to use the main doors. The Pathfinder visualizations also revealed the locations for the locally largest occupant loads in these scenarios. The other simulation scenarios can be observed from Appendix 4.

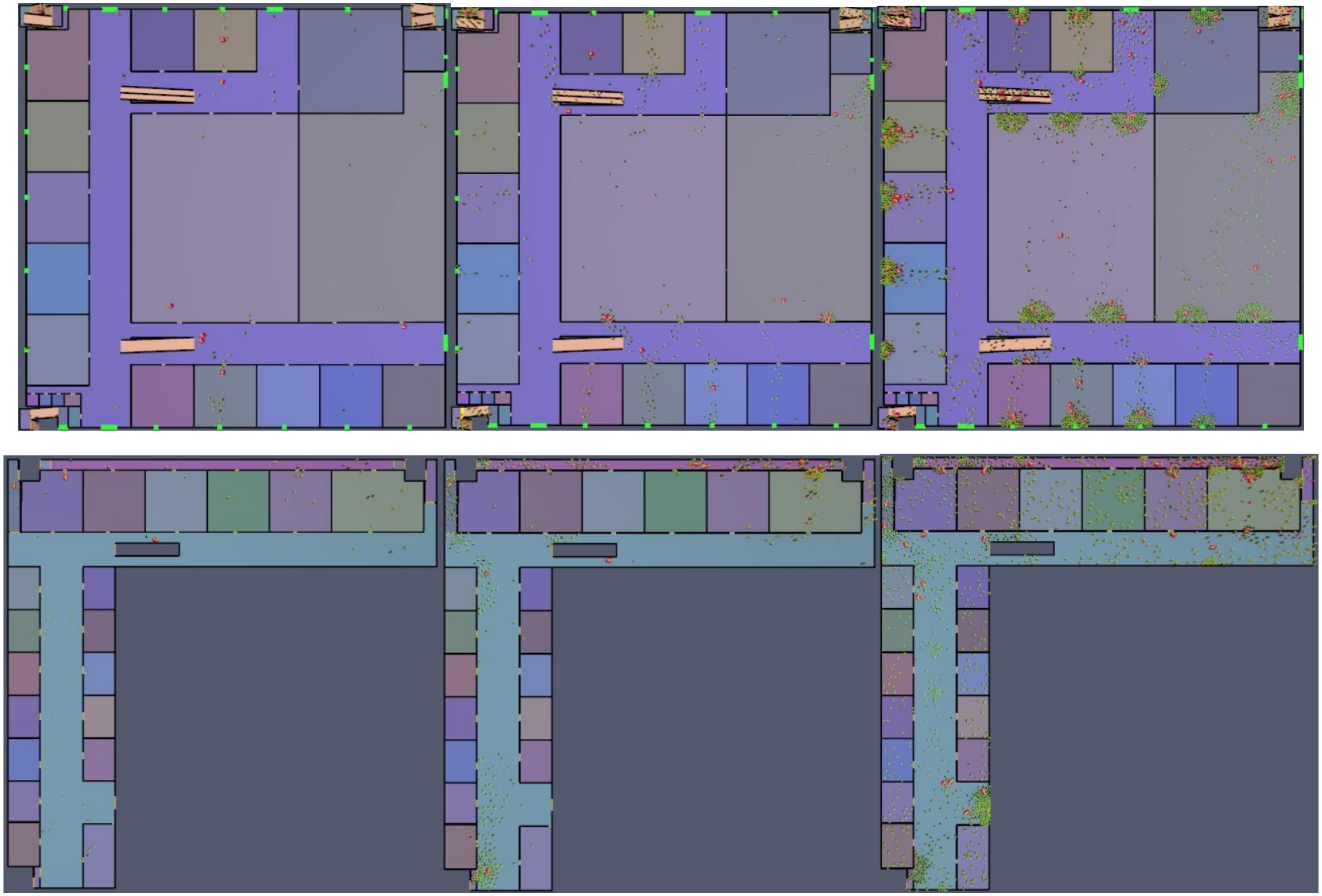

Figure 11. Comparison of different occupant densities. (Occupant density 0.0227/0.125/20.4 person/m^2, Route choice: Locally quickest path, Physical Distancing: No)

5.2.2 Analysis of the impact of the occupant load using hand calculations

Alongside with the egress simulations, the RSET was studied with simple hand calculations and the simulation results were compared with the hand calculations. Since the simulation scenarios begins from the alarm the detection time and notification times are neglected and are not included to the RSET. The premovement time is taken according to the slowest possible occupant and the occupant are assumed that they divide evenly within one specific door type. When the simulation scenarios were observed (picture 11, appendix 4) it was noted that in the simulation scenarios "Locally quickest path" and "Go to main" the queues forms in front of the doors and therefore, it was assumed that most restrictive egress component is one of the doors. However, for scenarios "70/30" and "Go to main" the largest queues were formed around the walkways on the northern corridor. The specific flow of 1.3 is assumed in all scenarios (Gwynne &Rosenbaum, 2016). The assumptions are listed in table 27.

Table 27. Assumptions for the hand calculations

Assumptions:
1. The simulation begins from the alarm, therefore notification time and detection time are not considered in the RSET.
2. Pre-movement time is considered to be the slowest possible. (Slowest possible value is taken from variation range)
3. Occupants divide evenly within the specific door type (Main, back or stair room)
4. The most restrictive egress component is a door for simulation scenarios "Locally quickest path" and "go to closest."
5. The most restrictive egress component is a walkway for simulation scenarios "70/30" and "go to main."
6. The specific flow is 1.3 persons/s/m (maximum) and speed is 1.19 m/s

The equation to solve RSET is:

$RSET = t_d + t_n + t_{p-e} + t_e$ (Equation 8) (Gwynne &Rosenbaum, 2016)

Where

RSET = Required safe egress time
t_d = Time to detection (0s)
t_n = Time to notification (0s)
t_{p-e} = Pre-movement time (111s)
t_e = Time to go through the most restrictive egress component
The time t_e is the time that it takes for the occupants to move through the most restrictive evacuation component. This time does not take into account the pre-movement time or the time

that it takes for the occupant to move to the egress component. For the door calculating the t_e, is simple, and it can be made simply by dividing the population with the calculated flow. For the walkway is calculated almost similarly. The only difference is, that the travel time that it takes for the occupants to walk through the walkway needs to be added to the final time. To calculate the effective width the boundary layers need to be subtracted each side from the total width of the component. For walkways the boundary layers are deducted twice. That is because there are two walkways right next to each other. The equations of t_e, specific flow and walking speed that are used in calculations and equations for effective width and calculated flow is shown in table 28. The effective widths for the doors and walkways are presented in the table 29 and calculated flow in table 30 (Gwynne &Rosenbaum, 2016).

Table 28. Input data for the hand calculations (Gwynne &Rosenbaum, 2016)

t_e	Door: Population / FC Walkway: Population / FC + travel time through the walkway	Evacuation time
Fs	1.3 persons/s/m	Specific flow
S	1.19 m/s	Walking speed
We	Door width - (2*boundary layer) Walkway width - (4*boundary layer)	Effective width
FC	FS*We	Calculated flow

Table 29. Calculated effective widths

Door width			Walkway width
Main door	Back door	First floor door	Walkways
3.9m	1.2m	2.5m	3m
Effective width (We)			
3.6m	0.9m	2.2m	2.2m

Boundary layer for doors: 0.15m (Gwynne &Rosenbaum, 2016)
Boundary layers for walkway: 0.2m (Gwynne &Rosenbaum, 2016)

Table 30. Calculated flows in different egress components

Main door (persons/s)	Backdoor (persons/s)	Stair room door (persons/s)	Walkway (persons/s)
4.68	1.17	2.86	2.86

In the scenarios “Locally quickest path” and “Go to closest” occupants were assumed that they divide evenly within the specific door type. To estimate how many people used main, back or stair room doors in evacuation, the random pathfinder results notes were investigated in order to find the number of occupants at each door type. The occupants numbers at the different doors for the scenarios “locally quickest path” and “go to closest” are presented in table 31 for the occupant density of 0.125 person/m^2 and in table 32 for 0.4 person/m^2.

In the scenarios “70/30” and “Go to main” the most restrictive egress component according to the observations from evacuation simulations were the walkway on the northern corridor. The reason for this is because a large part of the people is escaping through the main doors and therefore a large number of occupants are going from ground floor to the first floor. Since it was clearly seen that the largest queues were formed around the walkway, it was assumed that two thirds of the occupants who are escaping through the main door from the first floor are using the walkways. The occupant number at the walkway in the scenarios “70/30” and “Go to main” are presented in table 33.

Table 31. The number of occupants at different doors with the occupant density of 0.125 person/m^2

Locally quickest path					
Number of doors	Occupants (main doors)	Number of doors	Occupants (Back door)	Number of doors	Occupants (Stair room door)
5	460	14	800	5	534
Occupant per door	92	Occupant per door	57	Occupant per door	107
Go to closest					
Number of doors	Occupants (main doors)	Number of doors	Occupants (main doors)	Number of doors	Occupants (main doors)
5	439	14	811	5	544
Occupant per door	88	Occupant per door	54	Occupant per door	109

Table 32. The number of occupants at different doors with the occupant density of 0.4 person/m²

Locally quickest path					
Number of doors	Occupants (main doors)	Number of doors	Occupants (Back door)	Number of doors	Occupants (Stair room door)
5	1803	14	2469	5	1468
Occupant per door	361	Occupant per door	176	Occupant per door	294
Go to closest					
Number of doors	Occupants (main doors)	Number of doors	Occupants (main doors)	Number of doors	Occupants (main doors)
5	1762	14	2148	5	1830
Occupant per door	352	Occupant per door	153	Occupant per door	366

Table 33. The number of occupants at walkway in different scenarios

70/30	
0.125 person/m²	0.4 person/m²
251 Occupants	804 Occupants
Go to main	
0.125 person/m²	0.4 person/m²
359 Occupants	1148 Occupants

The evacuation time t_e is calculated by dividing the occupant load at the door with the calculated flow. The evacuation times are presented in table 34 for occupant density of 0.125 person/m^2 and in table 35 for 0.4 person/m^2. The door where there is the highest value of t_e, restricts evacuation the most, and therefore that value is chosen for t_e when the final RSET is calculated.

Table 34. Calculated t_e at the egress doors with 0.125 person/m²

0.125 person/m²	Main door (s)	Backdoor (s)	Stair room door (s)
Locally quickest path	20	49	37
Go to closest	19	50	38

Table 35. Calculated t_e at the egress doors with 0.4 person/m²

0.4 person/m²	Main door (s)	Backdoor (s)	Stair room door (s)
Locally quickest path	77	150	103
Go to closest	75	130	128

To calculate the t_e for the walkway, the travel time that takes to walk through the walkway needs to be included in the calculations. The travel time is calculated simply by dividing the length of the walkway with the walking speed:

Travel time: $15m\ /\ 1.19\ m/s\ = 12.6s$

Therefore, the t_e for the walkway is calculated with the equation 9:

$(Occupant\ number\ /\ Fc) +\ travel\ time$ (Equation 9)

The t_e are presented in table 36 for occupant density of 0.125 person/m² and in table 37 for occupant density of 0.4 person/m².

Table 36. Calculated t_e at the walkway with 0.125 person/m²

0.125 person/m²	Main door (s)
70/30	100
Go to main	138

Table 37. Calculated t_e at the walkway with 0.4 person/m²

0.4 person/m²	Main door (s)
70/30	294
Go to main	414

Finally, the RSET is calculated with the equation 8. The RSET values for 0.125 person/m² are presented in table 38 and for 0.4 person/m² in table 39.

Table 38. RSET with 0.125 person/m²

Locally quickest path	160
70/30	211
Go to closest	161
Go to main	249

Table 39. RSET with 0.4 person/m²

Locally quickest path	261
70/30	405
Go to closest	242
Go to main	525

In table 40 the simulated RSETs are compared against the hand calculated RSETs. It can be noted that the simulation results are more conservative than the results in hand calculations. The limitation of the hand calculations was that the value of the evacuation time t_e was assumed to be equal with the time taken from the occupants to go through from the most restrictive egress component. Because of this assumption the time that it takes for the occupants to move to the door were left out from the simulation scenarios "locally quickest path" and "Go to closest." In the scenarios "70/30" and "Go to main" the time that it took for the people to move from the starting point to the walkway and the time that it took for the last occupant to move from the ending of the walkway to the exit door were left out. Adding these times to the hand calculations would make the results more even. The other reason, that could explain the less conservative results with hand calculations is that in reality, the occupants do not separate evenly within the specific door type. Because of this some of the queues behind the doors in simulations might be larger than the queues that were used in calculations, which increase the RSET in simulations.

Table 40. Comparison of simulated RSETs and calculated RSETs

	Simulation 0.125 person/m² (s)	Calculation 0.125 person/m² (s)	Simulation 0.4 person/m² (s)	Calculation 0.4 person/m² (s)
Locally quickest path	204	160	319	261
70/30	282	211	488	405
Go to closest	216	161	435	242
Go to main	347	249	704	525

5.2.3 Impact of the door width to the evacuation

The impact of the door width to the evacuation was studied by investigating the correspondence between the total door width and the occupant load. This was investigated by running the simulations of each route choice scenario with the occupant density of 0.125 person/m^2 and no physical distancing. With each run the door width is decreased. The goal was to find out how much door width needs to be decreased so that the RSET corresponds with the occupant density of 0.125 person/m^2 and 0.4 person/m^2 in this specific simulation model.

In the first step the draft runs were made to find out, when the evacuation times with decreased door width start to get close to equal with the RSET times that were simulated with the total door width and regulated occupant load factor. The results of the draft runs are presented in table 41.

Interesting observation based on the results of the draft runs that was noted was, that when the simulations were run with the door width from 90% to 30% of the total door width, there was almost no increase in the RSET time. When the door width was decreased below the 30% from the total door width the RSET times started to increase faster. From the Pathfinder visualizations in figures 12-14 it can be observed, that when the door width was decreased to the 60% from the original the door width was still enough for the occupant load, and people did not get stuck to the queues. When the door width is decreased to 30% from the original, the occupants start to gather together in front of the door and queues begin to be formed. If the door width is decreased even more the queues will get larger, and therefore the evacuation times start to increase faster. The other scenarios can be found in Annex 6.

After the draft values were studied, the values that were closest to the goal values were taken to the further investigation and the convergence studies were made (Appendix 3). The results after the convergence study are presented in table 42. The first row shows that when the occupant density of 0.125 person/m^2 is used, the occupant load is 31 % from the occupant load that is estimated with the occupant load factor of 0.4 person/m^2. The four rows below show the percentage from the original door width that is needed so that the RSET with the occupant density of 0.125 person/m^2 equals the RSET time with the occupant density of 0.4 person/m^2. The table shows that the RSET times equals with each other when the total door width is 15 % - 20 % from the original in the scenarios “Locally quickest path” and “Go to main" and 20 % - 25 % when the scenario “70/30” is used. When only the main doors are used 14 % to 15 % from the original door width is enough with the occupant density of 0.125 person/m^2.

Table 41. The draft run results when the door width was decreased.

% from the total door width	Route choice	Draft RSET time (s)	% from the total door width	Route choice	Draft RSET time (s)
90 %	Locally quickest path	210	90 %	70/30	266
60 %	Locally quickest path	200	60 %	70/30	252
30 %	Locally quickest path	227	30 %	70/30	317
20 %	Locally quickest path	306	25 %	70/30	455
15 %	Locally quickest path	375	20 %	70/30	537
90 %	Go to closest	212	30 %	Go to main	406
60 %	Go to closest	212	25 %	Go to main	433
30 %	Go to closest	229	20 %	Go to main	558
20 %	Go to closest	436	15 %	Go to main	691
15 %	Go to closest	446	14 %	Go to main	705

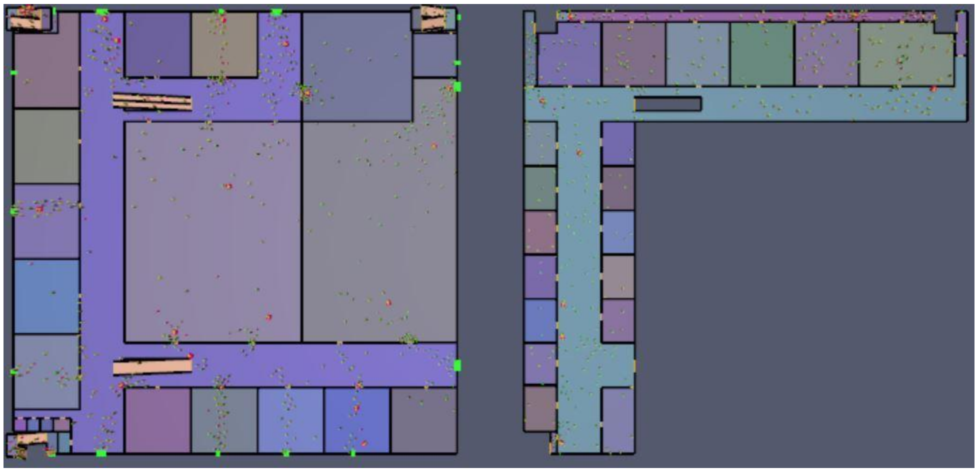

Figure 12. Occupant density: 0.125 person/m^2, Route choice: Locally quickest, Physical distancing: No, Door width: 60%

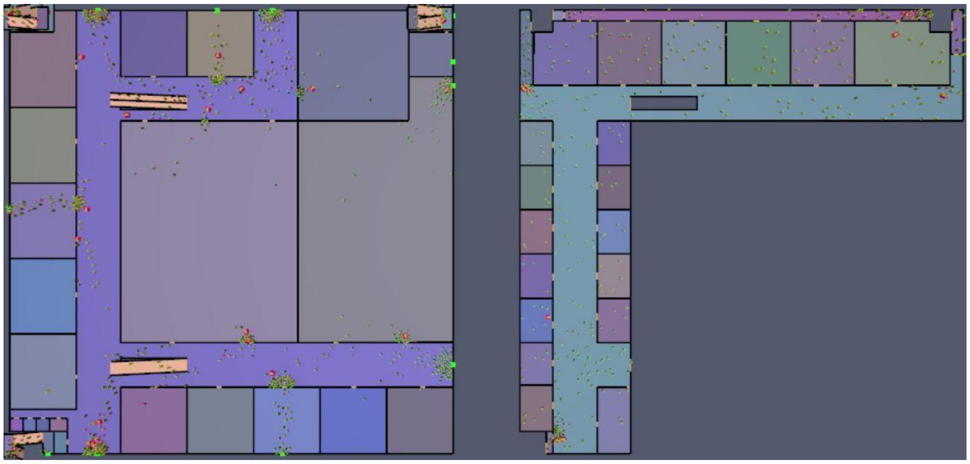

Figure 13. Occupant density: 0.125 person/m^2, Route choice: Locally quickest, Physical distancing: No, Door width: 30%

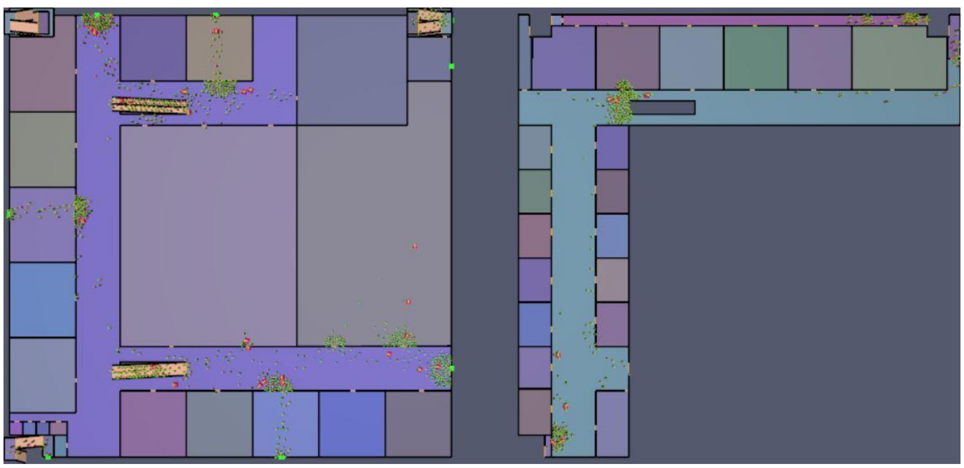

Figure 14. Occupant density: 0.125 person/m^2, Route choice: Locally quickest, Physical distancing: No, Door width: 20%

Table 42. Correspondence of the door width and occupant density in the studied simulation model

Route choice	Occupant density	Number of occupants	Occupant load factor	Number of occupants	Ratio
All	0.125 person/ m^2	1794	0.4 person/m^2	5740	31%
Route choice	Total Door Width	RSET	Total Door width	RSET	Ratio
Locally quickest path	7.3 - 9.7 m	303 - 363 s	48.8 m	319 s	15%-20%
70/30	9.7 - 12.3 m	472 - 556 s	48.8 m	488 s	20%-25%
Go to closest	7.3 - 9.7 m	393 - 466 s	48.8 m	435 s	15%-20%
Go to main	2.7-2.9 m	673 - 707 s	19.5 m	704 s	14%-15%

5.2.4 Impact of physical distancing on evacuation

The impact that pandemic has on the evacuation was also studied with the Pathfinder. The special interest was focused on the effects of physical distancing during the evacuation. The basic instructions guide people to leave the building as fast as possible when the fire alarm activates. This means that during the evacuation, people may be more focused on evacuation and not be worried about physical distancing, since the possible fire inside the building can be considered as a greater threat to the people's lives and health than the possible exposure to the virus during the evacuation. However, often if the sound is the only cue from the fire, people might be ignoring the cue and think that the alarm must be a false alarm. (Canter et al., 1980) Therefore, some people might keep physical distancing during the evacuation, e.g., if they do not take the possible fire threat seriously. In the present example, 5% of the people were considered to keep a distance of 2 meters during the evacuation.

The impact of physical distancing of 5% of the occupants was studied with Pathfinder simulations. Small percentage of people physical distancing was decided because in the earlier results it was seen that even during normal situations not all people are complying with physical distancing and even if they area, they are not able to keep the distance of 2 meters. In addition, in the case of fire, if the people are able to see the stronger cues from the fire like fire and smoke, it is more likely that they will take the fire seriously and therefore wants to escape as fast as they can and therefore they do not care about the physical distancing (Georgieva et al., 2021, Ronchi et al., 2021, Canter et al., 1980). In the tables 43-47 the evacuation times with fixed occupant loads and route choice is presented. In the left side of the table is the scenario, where the physical distancing is not applied and in the right side is the scenario where the physical distancing is applied. The difference between the two scenarios is presented in seconds and percentages. If the difference is presented with negative value, it means that the RSET is shorter considering physical distancing than in normal conditions.

Table 43. Effect of physical distancing with the occupant density of 0.4 person/m^2

	Pre-Covid (0.4 p/m^2)	Covid (0.4 p/m^2)	Difference (s)	Difference (%)
Go to any	319 s	363 s	44	12%
70/30	488 s	549 s	62	11%
Go to closest	435 s	494 s	59	12%
Go to main	704 s	812 s	108	13%

Table 44. Effect of physical distancing with the occupant density of 0.125 person/m^2

	Pre-Covid (0.125 p/m^2)	Covid (0.125 p/m^2)*	Difference (s)	Difference (%)
Go to any	204 s	209 s	6	3%
70/30	282 s	287 s	5	2%
Go to closest	216 s	214 s	-2	-1%
Go to main	347 s	370 s	23	6%

Table 45. Effect of physical distancing with the occupant density of 0.112person/m^2

	Pre-Covid (0.112 p/m^2)*	Covid (0.112 p/m^2)	Difference (s)	Difference (%)
Go to any	196 s	205 s	9	4%
70/30	262 s	275 s	13	5%
Go to closest	195 s	213 s	17	8%
Go to main	343 s	351 s	8	2%

Table 46. Effect of physical distancing with the occupant density of 0.0227person/m^2

	Pre-Covid (0.0227 p/m^2)	Covid (0.0227 p/m^2)*	Difference (s)	Difference (%)
Go to any	173 s	159 s	-14	-9%
70/30	225 s	226 s	2	1%
Go to closest	177 s	179 s	2	1%
Go to main	248 s	251 s	4	1%

Table 47. Effect of physical distancing with the occupant density of 0.013 person/m²

	Pre-Covid (0.013 p/m²)*	Covid (0.013 p/m²)	Difference (s)	Difference (%)
Go to any	178 s	160 s	-18	-11%
70/30	200 s	224 s	25	11%
Go to closest	164 s	183 s	19	11%
Go to main	243 s	262 s	19	7%

When the RSETs with the regulated occupant load factor 0.4 person/m² is observed it can be noted that since the occupant density is the highest with the regulated occupant load factor, also the average RSET time is the highest. When the occupant load factor was used it seemed clear that physical distancing has a clear impact on RSET since the RSETs were over 10% longer with all route choice scenarios. This means that the evacuation time has increased with the route choice scenario "Locally quickest path " for about 44 seconds and with the route choice scenario "Go to main " for about 108 seconds. The RSET increased the least with the scenario "Locally quickest path " and most with the scenario "Go to main ".

According to these results, it seemed clear that the physical distancing of 5% of the people will increase the RSET of the occupants. In order to understand the reason why the RSET is increased, it was further studied by investigating the Pathfinder simulations. From the simulation scenarios, it was observed that consistently the people who are physical distancing are the last people who leave the building. The reason for this is that, when the occupants start to exit the building, they will gather together in narrow locations inside the building that cannot be avoided on the way out. Such places could be in front of the doors, staircases, and walkways. This phenomenon can be seen in figures 15 and 16. Different door usage and queues are presented in Appendix 5 for each scenario.

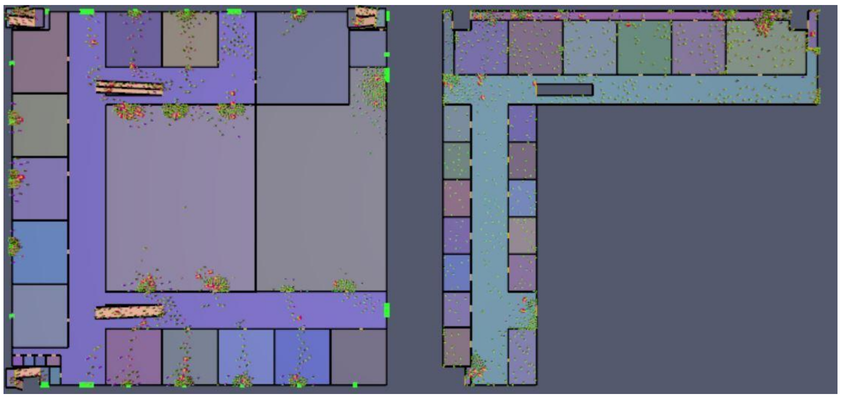

Figure 15. How people separate to the exits, Occupant density: 0.4 person/m², Route choice: Locally quickest path, Physical distancing: yes

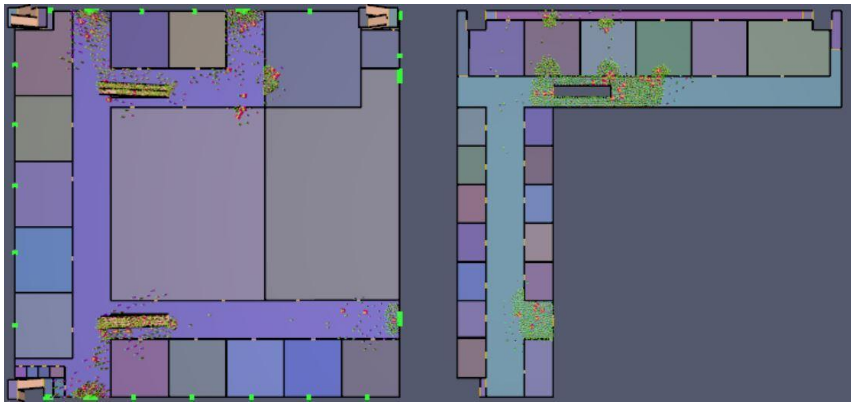

Figure 16. How people separate to the exits, Occupant density: 0.4 person/m^2, Route choice: Go to main, Physical distancing: yes

When people come together to these places, they start to form a queue, where they need to wait, in order to get out of the building. The people who are physical distancing can not join the queue, since they want to keep their distance from the other people. Therefore, they form another group behind the crowd, where they wait for the queue to go before them (figure 17A). After the queue has gone, people who are physical distancing may continue the evacuation. However, if the location where they are about to enter is narrow and long like a staircase or walkway, the people will fill the space ineffectively and the evacuation time is increased (figure 17B).

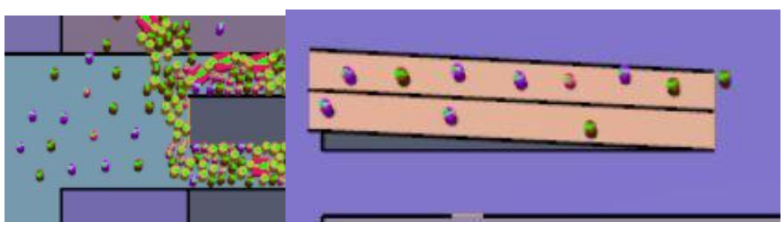

Figure 17. (A,B). People who are physical distancing form their own queue behind the main queue. After the main queue has gone, people who are physical distancing may continue evacuation, but they continue physical distancing

When the different route choice scenarios are investigated it can be noted that RSET increased the most with the route choice “Go to main” where occupants were only able to use the main exits. The second-largest increase was observed with the scenario “70/30” where 70% of people went to the main exits and 30% went to any exit. The RSET increased the least with the scenario where occupants were able to choose the locally quickest path. According to this, it seems that if the number of exits is restricted the RSET will be higher and physical distancing has a larger impact on evacuation time as well. When the Pathfinder visualizations are investigated in appendix 4 it can be observed that when the door choices are restricted like in scenarios “70/30” or “Go to main” where occupants cannot choose the any door they want, more people are gathering together at the same exits and this makes the queues larger and therefore evacuation times longer. However, also the number of people who are physical distancing is larger, which increases the impact of physical distancing, since it takes more time for them to continue moving after the queue has left, because of the spacing around the occupants who are physical distancing.

When the occupant density was decreased to 0.125 person/m^2 or 0.112 person/m^2 the RSET of different simulation scenarios decreased due to smaller occupant load, when compared with the simulations where occupant density of 0.4 person/m^2 were used. The RSET times were smaller in all scenarios with the occupant density of 0.112 person/m^2 which was expected since the occupant load was smaller. Since in all cases the RSET time increased or remained the same when the physical distancing were applied it was considered that the physical distancing increases the RSET. When the simulation results are observed it can be noted that the increases in RSET are in contradiction. With occupant density of 0.125 person/m^2 there are only small change in the scenarios “locally quickest path,” “70/30” and “go to closest” and larger increase in RSET in scenario “Go to main.” Similar results were observed with the occupant density of 0.4 person/m^2 and therefore these results were predicted. However, when the occupant density is decreased to the 0.112 person/m^2 there are only smaller changes in RSET in scenarios “Locally quickest path,” “70/30,” and “go to main” and larger increase in RSET with the scenario “Go to closest.” The difference for this result was investigated with the Pathfinder simulations and significant differences in occupant behavior was not observed. Occupants who were physical distancing got stuck behind the crowds to the same locations as in the simulations scenarios with the occupant density of 0.125 person/m^2. People who were physical distancing exit the building last and filled the staircases ineffectively which took more time to escape than when occupants were not physical distancing. Therefore, the amount of the impact of physical distancing cannot be estimated with the lower occupant loads because it is assumed that also the variation in occupant characteristics may affect to the RSET time.

When the occupant load is decreased, and the occupant density is 0.0227 person/m^2 or higher the number of occupants is so small that the occupants are not making queues in any evacuation scenarios. When the simulation results are investigated, it can be observed that there are quite significant differences in RSETs between simulation scenarios where physical distancing has been applied and where it has not. However, the impact of physical distancing to the RSETs is questioned. When the Pathfinder visualizations are investigated from appendix 4, it can be observed that with low occupant load, people have a lot of space around them. Therefore, occupants who are physical distancing do not need to avoid other occupants and they are able to exit smoothly.

It was concluded that with low occupant load the occupant characteristics have a larger impact on the simulation results. This was also noted when the convergence of the simulation scenarios was studied (see appendix 2). It can be observed that the simulation scenarios where the occupant load was low, needed more simulation runs, because there was more variation in simulation results and therefore the results did not converge as fast as with the other simulation scenarios. It is also a logical conclusion, that if the occupant density is low, the occupant characteristics have a greater impact on evacuation. For example, if the occupants are able to react fast to the fire and are close to the exit, they can exit the building much faster than if the occupants are not able to react quickly to the fire, they are located far away from the exits and their movement speed is low. Since these variables are determined at random for each simulation run, it might lead to variation in RSETs especially when the occupant density is lower.

When the RSET times before the pandemic and considering physical distancing during the pandemic are investigated two comparisons are made. The maximum measured occupant density before the pandemic is compared with the maximum measured occupant density during the pandemic. With this comparison, the RSET times can be compared with the worst credible case that has actually happened and how the evacuation times differ. In the second comparison, the mean occupant density before the pandemic is compared to the mean occupant density during the pandemic in order to see how the pandemic has affected the evacuation time on an average day.

In table 48, the measured maximum occupant density before the pandemic is compared with the measured maximum occupant density during the pandemic. Based on the observations made before, the higher occupant density predicts a higher RSET. However, when the occupant density is high enough the physical distancing increases the RSET as well. It was observed earlier, that with the occupant density of 0.112 person/m^2 in all scenarios where the physical distancing was applied the RSET increased. When the values are compared it can be noted that the RSETs are higher before the pandemic for the scenarios “70/30” and “Go to closest” and during the pandemic for the scenarios “Locally quickest path” and “Go to main”. The differences between all the scenarios are very small since at the highest difference is 2% which means 7 seconds. Since the difference in the RSET before the pandemic and during the pandemic was very small it was concluded that the impact of physical distancing on the RSET with the higher credible occupant density was negligible.

Table 48. Comparison of RSET with the maximum occupant density before the pandemic and during the pandemic

	Pre-Covid (0.125 p/m^2)	Covid (0.112 p/m^2)	Difference (s)	Difference (%)
Go to any	204 s	205 s	1	1%
70/30	282 s	275 s	-7	-2%
Go to closest	216 s	213 s	-3	-2%
Go to main	347 s	351 s	4	1%

The difference of the measured mean occupant density before the pandemic and during the pandemic are compared in table 49. Since the difference between the occupant density are higher than in previous comparison, it is expected to see higher RSET times with the occupant density of 0.0227 person/m^2. This prediction is enforced by the earlier observation where it was noted that with the lower occupant density, the physical distancing does not have an impact on the RSETs since the people have space to keep physical distancing while moving towards the exit. However, the comparison shows that the only scenario where lower occupant density led to the smaller RSET was the scenario "locally quickest path". The difference between the case where people divided to the main exits and any exits was negligible and therefore the evacuation times were considered to be the same. When the occupant escaped to the closest exit the RSET was 6 seconds smaller with the mean value before the pandemic and when the occupants went only to the main exit the difference was 15 seconds. It was earlier concluded that when the occupant density is low the impact of occupant characteristics and locations becomes larger.

Table 49. Comparison of RSET with the average occupant density before the pandemic and during the pandemic

	Pre-Covid (0.0227 p/m^2)	Covid (0.013 p/m^2)	Difference (s)	Difference (%)
Go to any	173 s	160 s	-13	-8%
70/30	225 s	224 s	1	0%
Go to closest	177 s	183 s	6	3%
Go to main	248 s	262 s	15	6%

6. DISCUSSION

In the beginning of this study three research questions were placed where this study was supposed to find the answers. The questions were:

1. How do the occupant load factors determined by Finnish regulations compare to the occupant load factors determined by international standards and other national regulations?
2. How well regulation based occupant load factors correspond with the real occupant loads in retail buildings?
3. What impact did the pandemic have on occupant density in Finnish retail buildings and what consequences would this have on fire evacuation design?

When compared with the earlier research, the correspondence of occupant load factor and real occupant densities has been earlier researched in retail buildings in Switzerland (De Sanctis et al., 2019) and for offices in Spain (Alonso & Alvear, 2013). Therefore, the correspondence of occupant density in retail buildings has not been researched earlier in Finland.

Also, since this study is made after the outbreak of Covid19 pandemic the effect of the pandemic to the occupant load is researched and how it should be taken into account when fire evacuation design is practiced during the pandemic times.

6.1 Correspondence of occupant load factors in Finnish decree 848/2017 and in other national and international standards.

In this research the occupant load factors from Finnish national standard were compared with the occupant load factors from other national regulations and international building code. The first and the most impactful observation was that the occupant load factors are defined in very different ways in the other countries than in Finland which make comparing the occupant loads difficult.

In Finland occupant load factors were determined for each usage category that are determined in Finnish 848/2017 and each usage category contains multiple different types of buildings. Only differences were in the usage category assembly and business premises that were separated into two groups. General assembly and business premises and amusement, art, etc. assembly and business premises. The issue when the occupant load factors are compared is that in other countries occupant load factors are determined for more specific building types and Finnish occupant load factors contain a wide range of different types of buildings under one occupant load factor. A good example of this issue could be office buildings where the occupant load factor of 10 m^2/person was determined in 848/2017. When this value is compared for example with the BS9999/2017 there are three different occupant load factors determined for different types of office buildings: Cellular offices 10 m^2/person, Open plan offices 7 m^2/person and Call Centres 4 m^2/person. Therefore, the problem is which occupant load factor should be used, when correspondence is investigated. It can be clearly observed that the occupant load factor corresponds with the value of cellular office in BS9999:2017 but the occupant load factor does not correspond with the other values. The same issue can be observed with the assembly and business premises. In Finland the occupant load factor for general assembly and business premises is 2.5 m^2/person (0.4 person/m^2). When this value is compared with the regulations of other countries it can be noted that a wide spread of different types of buildings belong under the group “general assembly and business premises" like schools, shops and libraries. It seems unlikely to assume that all these different building types would share the similar occupant load, and when the comparison is made to the other national regulation it can be seen that occupant load factors vary from 2 m^2/person that is determined for clothing stores or classrooms, to 7 m^2/person or even 10 m^2/person that are determined for libraries.

Therefore, the key issue concerning the comparison of occupant load factors with the national regulations from other countries is that the occupant load factors are determined completely differently. However, the comparison revealed that in other countries the occupant load factors are determined separately for specific building type whereas in Finland jointly for the whole usage category. This is under the assumption that one occupant load factor for the whole usage category could be valid. This assumption seems unlikely.

6.2 Correspondence of the occupant load factor and real occupant loads in business premises in Finland

When the measured occupant loads were compared with the regulated occupant load factors the occupant densities were used, so that making the comparison possible. In shopping malls, it was observed that with the regulated occupant load factor the estimated occupant loads are significantly larger than when compared with the actual maximum occupant densities that were measured from the shopping malls. The result was expected, since similar results were observed in earlier research and code values generally account for conservatism (De Sanctis et al., 2014, 2019). Generally, if the occupant load in the building is not known it is good that the number of occupants is overestimated in order to add safety factors to the values, however too large safety factors often increases the cost of the project (Notarianni & Parry, 2016). Therefore, the safety factors need to be well justified, so that they guarantee the level of safety, but not increase the costs of the project in vain.

If historical data is available, it can be used when the appropriate safety factors are determined. One method that is used in fire safety engineering is the worst credible case, that is based on an assumption that if the worst credible case can be handled, every other scenario can be handled as well. (Notarianni & Parry, 2016). In the study, different occupant densities were studied with Pathfinder simulations. As expected, it was observed that when the occupant density is higher, the evacuation takes more time and therefore the highest measured historical occupant density can be considered as the worst credible case. However, since it cannot be guaranteed that the occupant density will not get higher than what has been historically measured, some kind of safety factor needs to be added in order to be sure that the occupants can escape the building fast enough, even if the occupant density is higher than what was measured earlier.

The historical data showed that the occupant load varies significantly depending on the day and the average occupant density in person per area varies a lot. Depending on the mall the average values varied between 0.063 person/m^2 to 0.014 person/m^2 in premises A-D where the occupant density values were gathered from each day. However, since the Finnish 848/2017 says the highest possible occupant load needs to be used when determining the door width, it can be observed that the highest occupant density in area per person was 0.124 person/m^2. When this is compared with the regulated occupant load factor of 0.4 person/m^2 it can be noted that the estimated occupant loads with the occupant load factor are over three times higher than the actual occupant loads. Since the highest measured occupant density is measured already during the most crowded day of 2019, it seems unlikely that the occupant load could be increased by a factor of 3.

Since the occupant load factors can be used to determine the minimum door width that is needed to the premise, the impact of the door width was studied by reducing the door width in the simulation model. It was observed that when the maximum measured occupant density was used (0.125 person/m^2) the occupant load was 31% from the original. The goal was to degrease the door width until the REST is equal with the occupant load factor. The equal RSET was found when the door width in the premise was found between 14%-25% from the original door width, depending on the route choice scenario. Therefore, it was concluded that when the occupant density is decreased, the door width that is needed in order to reach the same RSET decreases faster.

In conclusion it was observed that the regulated occupant load factor overestimates the occupant load over 3 times when compared with the highest occupant density that was measured from the Finnish shopping mall for this study. When the impact of the door width to the RSET was observed, it was noted that less than one fourth from the original door width was needed in order to reach the same RSET as with the regulated occupant load factor. Therefore, it is considered that the regulated occupant load factor does not correspond very well with the actual occupant loads in Finnish shopping malls. When the occupant load factor is compared with the occupant load factors provided by national standards of other countries and international standards, the best fit was found from NFPA 101, where the occupant load factor varied depending on the size of the mall. For smaller malls that are smaller than 14000 m^2, the occupant load factor is 2.8 m^2/person and for larger malls that are larger than 37000 m^2 the occupant load factor is 5.1 m^2/person.

6.3 The impact of the pandemic to the occupant density and evacuation design in Finnish business buildings

The impact of the pandemic was studied, by investigating the occupant density a year before the pandemic spread to Finland and during the first year of the pandemic. The expectation was that the occupant density would decrease significantly during the pandemic and therefore the RSET would decrease as well.

When the distribution of occupant density was received from malls, it was clearly observed that when the pandemic started in Finland, at first the occupant densities decreased drastically, but very soon the occupant densities increased back close to the normal. The highest occupant density before the pandemic was measured from mall E and was 0.124 person/m^2. The highest occupant density during the pandemic was measured from mall B and was 0.112 person/m^2. The difference in the occupant density was 182 people and about 10 %. However, the highest occupant density that was measured from mall B was measured during the pandemic and was the second highest occupant density measured by area per person from all the malls that were studied. Therefore, it was concluded that the difference between the maximum occupant load before and during pandemic were small and therefore, the exit roads and exit signage should not be disabled even if the customers freedom to move is restricted in the society and they are instructed to stay home and avoid public spaces.

During the pandemic, people are advised to keep physical distance towards other people. On the other hand, during the fire people are advised to escape the building as fast as possible. Therefore, the impact of physical distancing of the small number of people to the evacuation were studied. If the occupant load is low, clear evidence of the impact of physical distancing was not found. However, when the occupant load is low, people have more space around them and therefore, they can escape and keep the physical distance at the same time. On the other hand, with the high occupant load, occupants get stuck in queues in front of the doors, walkways and staircases. In the simulation scenarios people who were physical distancing, decided to wait behind the queue until the path was clear and exit last. This behavior increased the RSET time, because people who were physical distancing could not move until the path was clear for them. Finally, when they were able to move, they filled the staircases ineffectively, because they wanted to keep distance towards each other, and therefore the evacuation took more time. This kind of behavior is logical, as long as the occupants does not have any new information about the fire except the fire alarm. Since the behavior where some people keep physical distancing even during the fire alarm was justified by the fact that if people are not able to experience any other cues than the fire alarm, some will ignore the alarm or consider it to be the false alarm or the fire drill (Canter et al., 1980). Therefore, when they get to the queue, they may feel that the risk of being exposed to the virus is higher than the threat of potential fire, and therefore they have time to wait until they can escape and keep their distance. However, if the alarm is serious and people know that there is a fire in the building, it is deemed unlikely that people would consider the possible exposure to the virus a greater risk than the fire. Nevertheless, no data are currently available to back up this speculation.

In this study, the route choice scenarios were predetermined. It was observed that when more restrictive route choice scenario was used the larger queues were formed in front of the doors. Largest queues were formed when occupant used only the main doors and second largest when 70% of the occupants used the main doors. The route choice scenarios were justified with theory of affiliation, which means that the occupants exit the same way from where they came from. Since the occupants who are physical distancing are avoiding the physical contact it could be possible, that the occupants could try to find another way out, if they realize the huge queues in front of the doors they are going to use. Therefore, the physical distancing could also have an impact on how the occupants make their route choices during the evacuation.

In conclusion, it was observed that most of the times decreasing the occupant load, will decrease RSET. However, since some people are physical distancing during the pandemic the RSET are increased especially if the occupant load is high and people get stuck to the queues, since people who are physical distancing refuse to exit until the path is clear, and the evacuation takes more time, since occupants keep distance towards each other. The impact of the pandemic to the evacuation was investigated in this study. It was predicted that evacuation would be faster during the pandemic since the occupant loads decrease due to the policies that suggest occupants to avoid social contacts and advise occupants to keep physical distance towards other people.

The results of this research showed that in the beginning of the pandemic the occupant load in retail buildings decreased fast. However, the occupant loads started to increase soon after close to the values that were measured before the pandemic. The highest occupant load during the pandemic was measured before Christmas, when the occupant loads were elevated also before the pandemic. The highest occupant load during the pandemic was 0.112 person/m^2 and was measured from mall B and was the highest occupant load that was measured in mall B during the whole research period. The highest occupant load before the pandemic was 0.124 person/m^2 and was measured in mall E. The difference between the highest occupant load before and during the pandemic was only 0.012 person/m^2. In order to give perspective, in the simulation model the difference in occupant load was 10% when these two occupant loads were used in simulations.

Generally, when the occupant load decreases, the RSET decreases as well. However, during the pandemic people were advised to keep physical distance towards other people. Keeping the physical distance is not necessary in the case of fire evacuation, but it was assumed to affect the evacuation, since many times, if people are not able to see any other cues than hear the alarm, they will ignore the alarm or will not take it seriously. Therefore, it was assumed that a small percentage of the people will keep physical distancing. When the occupant load decreases, the number of people who are physical distancing decreases as well and less queues are formed and therefore the impact of physical distancing to the RSET is smaller.

In the case of fire, the goal is to empty the building as fast as possible. Generally, a smaller occupant loads helps with this goal, since usually RSET decreases when the occupant load is lower. However, even though the occupant loads decreased during the pandemic the historical data showed that high occupant loads can still be measured. The challenge in this case would be the people who keep physical distancing even during the evacuation. However, since it was noted that the effect of physical distancing was higher, when there were more queues it is important that the building is equipped with a sufficient number of exits. According to the Pathfinder simulation study, the number of the exits is not a key issue, since the regulated occupant load factor over-estimated the door width that is needed plus some extra doors might need to be installed, since the exit distances will be exceeded otherwise. This is assuming all exit routes are available during the full course fire. Since the total exit width is overestimated, when the occupant load is estimated with occupant load factor and the doors are separated evenly around the building, to make sure that exit distances will not be increased, the blockade at one exit might not cause issues in evacuation. However, since most of the occupants escapes from the door where they came from the occupant load concentrates in front of the main doors. If the fire blocks one of the main doors the occupant load from that door separates to the other main doors. This might cause large localized queues to some of the exits that can restrict the evacuation and increase the RSET. Therefore, the focus should be kept on how the occupants are guided to the nearest exit instead of the main exits. If the occupants can be guided to the closest exits the larger localized queues are not formed and evacuation becomes faster.

Since there are already regulations on how to define the total door width, exit distance and how the exits should be marked it is challenging to affect this issue with the fire evacuation design. However, one way to affect evacuation and make it more effective is to design appropriate voice alarms. They are already common in public buildings. The advantage of the voice alarm is that they can give information and instructions about the situation to the occupants (Nilsson, 2014). Therefore, with the voice alarm, occupants could be reminded that physical distancing is not needed during the fire evacuation since all the delays in the evacuation is not wanted. Since it was observed, that if the queues are formed the RSET is increased more. Therefore, perceptibility of the evacuation exit signage should be focused, so that occupants could be guided to the nearest exit more effectively. The lighting system of the building should be connected to the automatic fire alarm systems. In case of the fire alarm all the unnecessary lights should be switched off, so that they will not cause distractions over the evacuation lights. The advertisement boards should be either switched off, so that they will not distract occupants or alternatively used as an information boards that give information about the closest exits. The emergency lighting could be used with the evacuation signage to guide occupants to the nearest exit. The evacuation signs and emergency lights close to the exit could be brighter than the signs and lights that are more far away. However, the lights should provide enough light for each part of the building so that they will not endanger the evacuation.

6.4 Limitations of the research

The limitations of the study relates to the data collection, evacuation simulations and lack of research data related to the Covid19 pandemic. Firstly, the greatest challenge in this study was the data collection. It was hard and took a lot of time to keep in touch with business actors that could provide data from their facilities. The data was asked from 19 shopping mall premises and 4 department store branches that owned multiple premises. Only six actors accepted to provide the data. Since staying in touch with the business actors was time consuming, it was not possible to increase the number of premises where the data was asked.

Since carrying out the study relied heavily on the co-operation of the business actors only the data absolutely necessary was asked, in order to make sure that the actors will not change their mind about providing the data. Therefore, the maximum occupant density simultaneously in the building was asked from every day from 2019 and 2020. Two of the premises were able to provide only the maximum occupant density simultaneously in the building from every week.

In a year 2020 there were 112 shopping malls in Finland (Suomen Kauppakeskusyhdistys, 2021.). This study contained 6 of them from different parts of Finland. To make this study more meaningful the number of shopping malls participating to the study should be increased. Increasing the number of premises where the occupant densities were asked could have increased the accuracy of the study since more high occupant loads could have been found and there are plenty of shopping malls where the maximum occupant densities can be even higher than what studied in this research. However, I think the number of shopping malls that participated on this study are able to provide directional results on the occupant densities that are in Finland.

Alongside with adding the number of shopping malls, adding the years could have increased the accuracy of the study. Adding the years before the pandemic could were possible, but would have meant more work for the shopping mall premises that participated to the study, and therefore, longer period of data were not asked. The occupant data during the Covid19 pandemic could have increased as well, but it was decided that it is only asked from the year 2020, because the data were asked during the year 2021 which means 2020 was the only complete year where the occupant load data during the Covid19 could have been asked.

In evacuation simulations the occupants were modeled individually, which is unlikely, since people often visit the malls in groups and small children are often with their parents. Simulating the group behavior is possible but the Pathfinder, which often would lead into longer evacuation times however specific data and validation related to the grouping is still unknown according to the Pathfinder user guide.

Using the Pathfinder simulations consist some uncertainty that are related to the model that were used, which can limit the reliability of the study. Since in the Pathfinder simulation, human behavior is modelled in advance and the occupants are moving according to the pre-determined behavior and there are no quick changes in decisions. In real life occupants might do some quick changes in their plans and decide to use other door instead of another, if they think it might be quicker way to get out. Therefore, there is always some uncertainty in the simulations results caused by the fact that modelling human behavior perfectly is impossible. In order to tackle this issue, multiple different kind of simulation scenarios where studied, in order to get a picture on how long evacuation will take if the worst case happens.

Thirdly, lack of research data related to the Covid19 pandemic cause limitation, when the effect of physical distancing was studied, since it is not known if some percentage of the people would keep physical distancing even during fire evacuation. The justification is based on an assumption, that according to behavioral sequence theory, if occupants do not see any other cues from the fire, the alarm is ignored or considered to be a false alarm or a drill. Therefore, the small number of people might consider the potential exposure to be a higher risk than the fire alarm.

6.5 Further research suggestions

The further research topics that should be studied more are the correspondence of occupant load factors in other types of business and retail premises, impact of physical distancing to the evacuation, the maximum occupant densities before, during and after covid and to the ways to guide occupants more effectively during evacuation.

In the study, it was observed that the occupant load factors determined in the guidance document of 848/2017 are determined for wide spread of different types of buildings. It was observed that in other countries occupant load factors were determined more specifically for specific building use. Therefore, the occupant densities in different types of business and retail premises, like restaurants or schools, and their correspondence with the occupant load factors determined in Finnish 848/2017 should be further investigated.

Since the data on if the occupants are physical distancing during the evacuation during the pandemic were not found, it would be an interesting topic to research further, in order to justify the if the occupant are physical distancing during the evacuation on pandemic times and how large the number of people.

Secondly the effect of the Covid19 pandemic to the occupant load should be further researched. The amount of available data during the pandemic was limited, since the pandemic was still going on when the research data was gathered. The complete study on how the pandemic affected the occupant loads would be interesting and it would be interesting to see if the occupant loads are recovered back to the level that was observed before the pandemic.

Finally, it was suggested that in order to improve the effectiveness of the evacuation to avoid queues that restrict the flow, the occupants should be guided to the closest exit more effectively. The suggested solutions were to use advertisement boards as an exit signage and use brighter exit signage and emergency lights closer to the exit. The effectiveness of these suggestions has not been researched and therefore research should be made if those methods could make the evacuation more effective.

7. CONCLUSIONS

The main conclusions that were found out were that the occupant load factors are determined much more specifically for different buildings in other countries than in Finland. Therefore, it cannot be stated that the Finnish occupant load factors correspond well with the other national or international standards, since one usage group that is determined in Finland contains multiple different types of buildings with different occupant load factors determined in other countries.

The occupant load factor in general business and assembly buildings contains the business premises like shopping malls. The occupant load factor in general assembly and business premises is 0.4 person/m^2. In the study, six different shopping malls were studied, which were referenced in the study as shopping mall A-F. The highest occupant density in form of area per person that was measured was 0.125 person/m^2. Even though the occupant load factor needs to be conservative value, in order to make sure that the estimated occupant load factor represents the highest occupant load, the regulated occupant load factor overestimates the maximum occupant load that was measured with an over factor of three. Therefore, it is considered that the regulated occupant load factors are too conservative.

It was observed that during the pandemic the occupant loads varied significantly. When the first restrictions and suggestions were ordered by the Finnish government the occupant load decreased drastically in all shopping malls that were investigated. However, the occupant loads started to recover and by the end of the year the occupant loads were recovered close to the pre-covid values. In premise E the highest occupant load was measured during the pandemic which was the second highest occupant load overall that was measured during the research, and it was only 0.012 person/m^2 lower than the highest occupant load that was measured. Therefore, it was concluded that generally the occupant loads decreased because of the pandemic, however the high occupant loads are still possible during the pandemic. Because of this, the exit roads and exit signage should not be disabled even if the governments are restricting the customers right to move that impacts to the occupant load in retail spaces.

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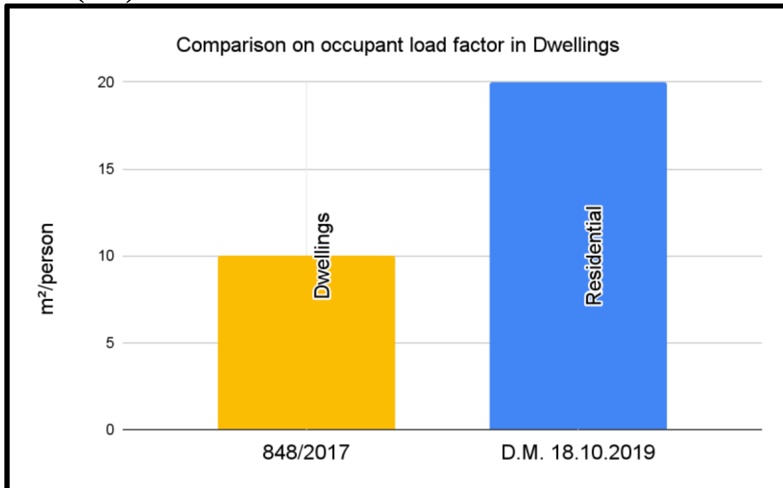
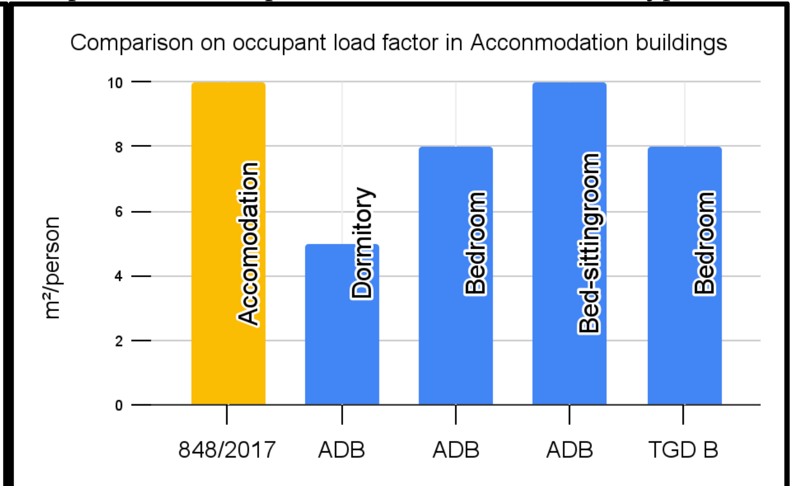
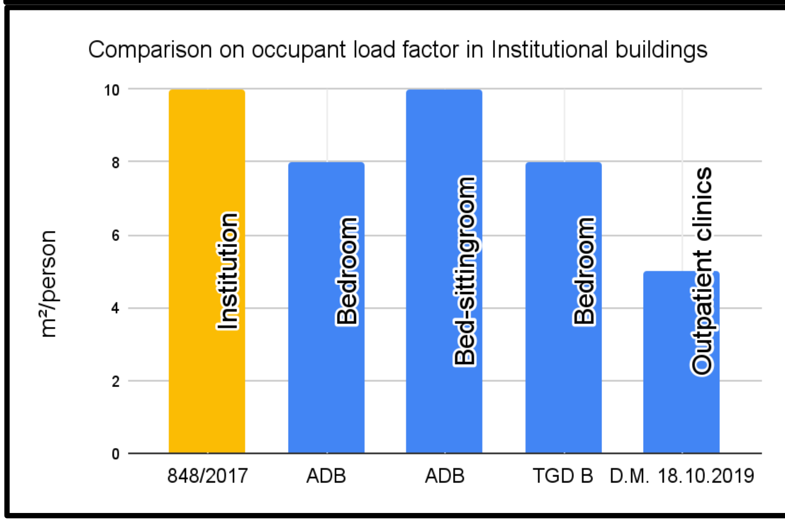
Appendices

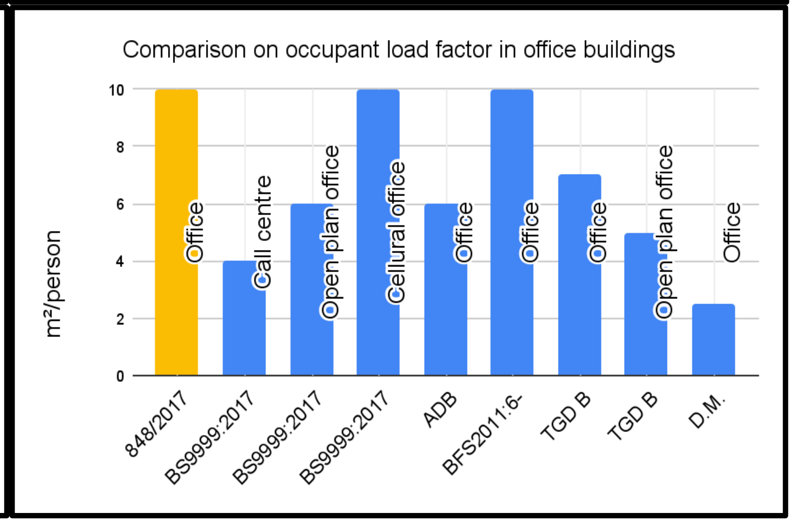
Appendix 1(1/3)

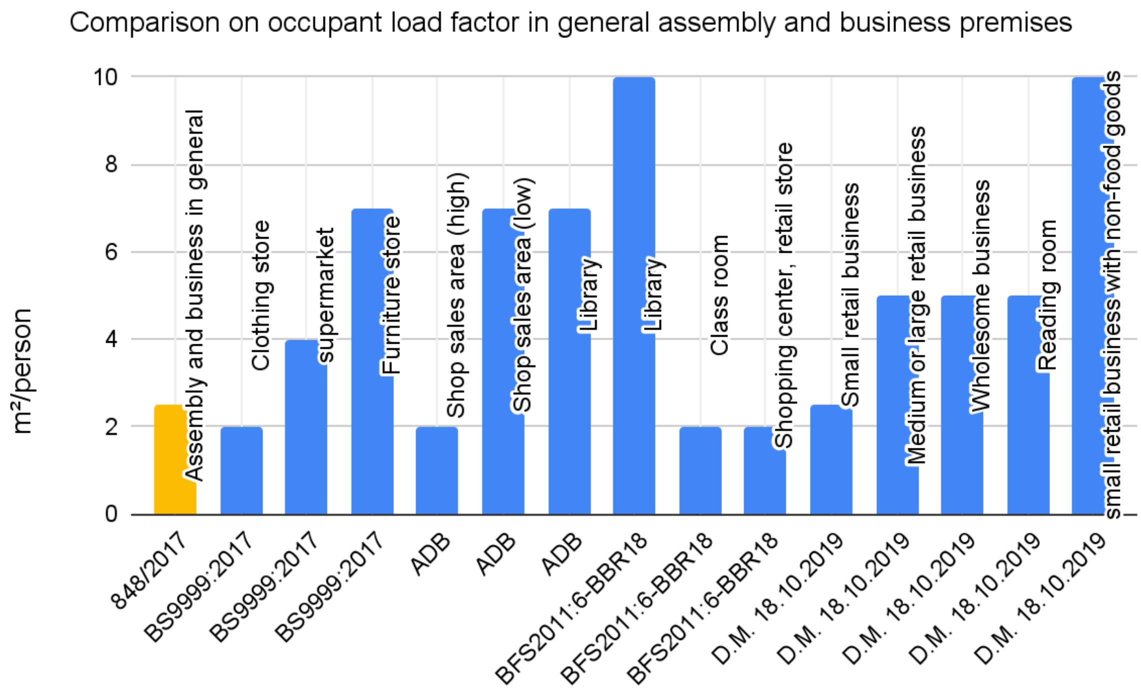
Comparison of occupant load factors in different types of buildings

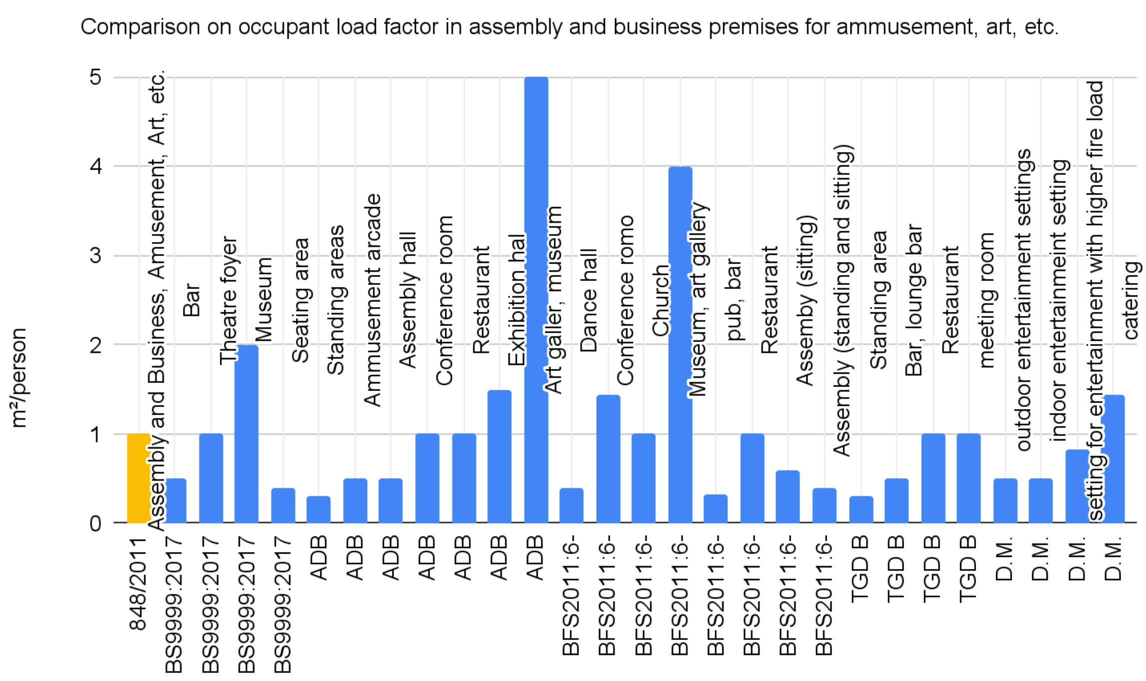









Comparison on occupant load factor in general assembly and business premises
m²/person
0
2
4
6
8
10
Assembly and business in general
Clothing store
supermarket
Furniture store
Shop sales area (high)
Shop sales area (low)
Library
Library
Class room
Shopping center, retail store
Small retail business
Medium or large retail business
Wholesome business
Reading room
small retail business with non-food goods
848/2017
BS9999:2017
BS9999:2017
BS9999:2017
ADB
ADB
ADB
BFS2011:6-BBR18
BFS2011:6-BBR18
BFS2011:6-BBR18
D.M. 18.10.2019
D.M. 18.10.2019
D.M. 18.10.2019
D.M. 18.10.2019
D.M. 18.10.2019


Comparison on occupant load factor in assembly and business premises for ammusement, art, etc.
m²/person
0
1
2
3
4
5
Assembly and Business, Amusement, Art, etc.
Bar
Theatre foyer
Museum
Seating area
Standing areas
Ammusement arcade
Assembly hall
Conference room
Restaurant
Exhibition hal
Art galler, museum
Dance hall
Conference romo
Church
Museum, art gallery
pub, bar
Restaurant
Assemby (sitting)
Assembly (standing and sitting)
Standing area
Bar, lounge bar
Restaurant
meeting room
outdoor entertainment settings
indoor entertainmeint setting
setting for entertainment with higher fire load
catering
848/2011
BS9999:2017
BS9999:2017
BS9999:2017
BS9999:2017
ADB
ADB
ADB
ADB
ADB
ADB
ADB
BFS2011:6-
BFS2011:6-
BFS2011:6-
BFS2011:6-
BFS2011:6-
BFS2011:6-
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TGD B
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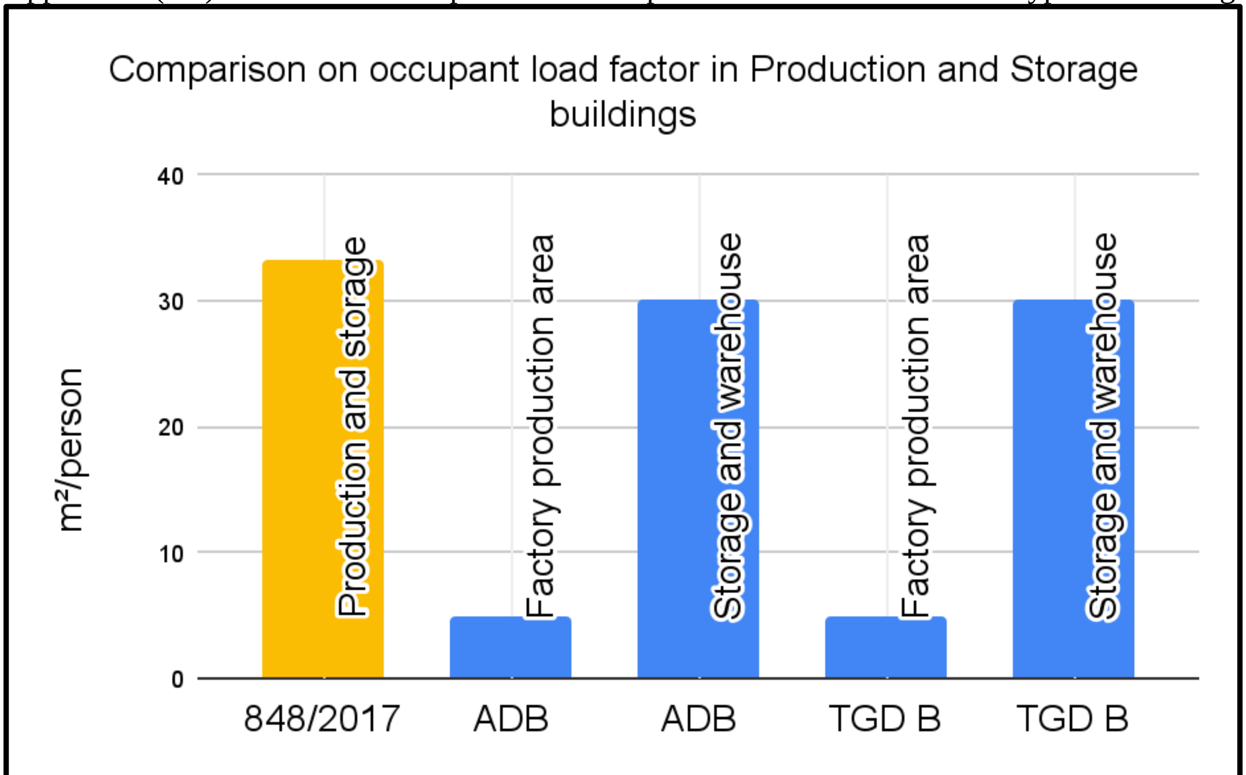
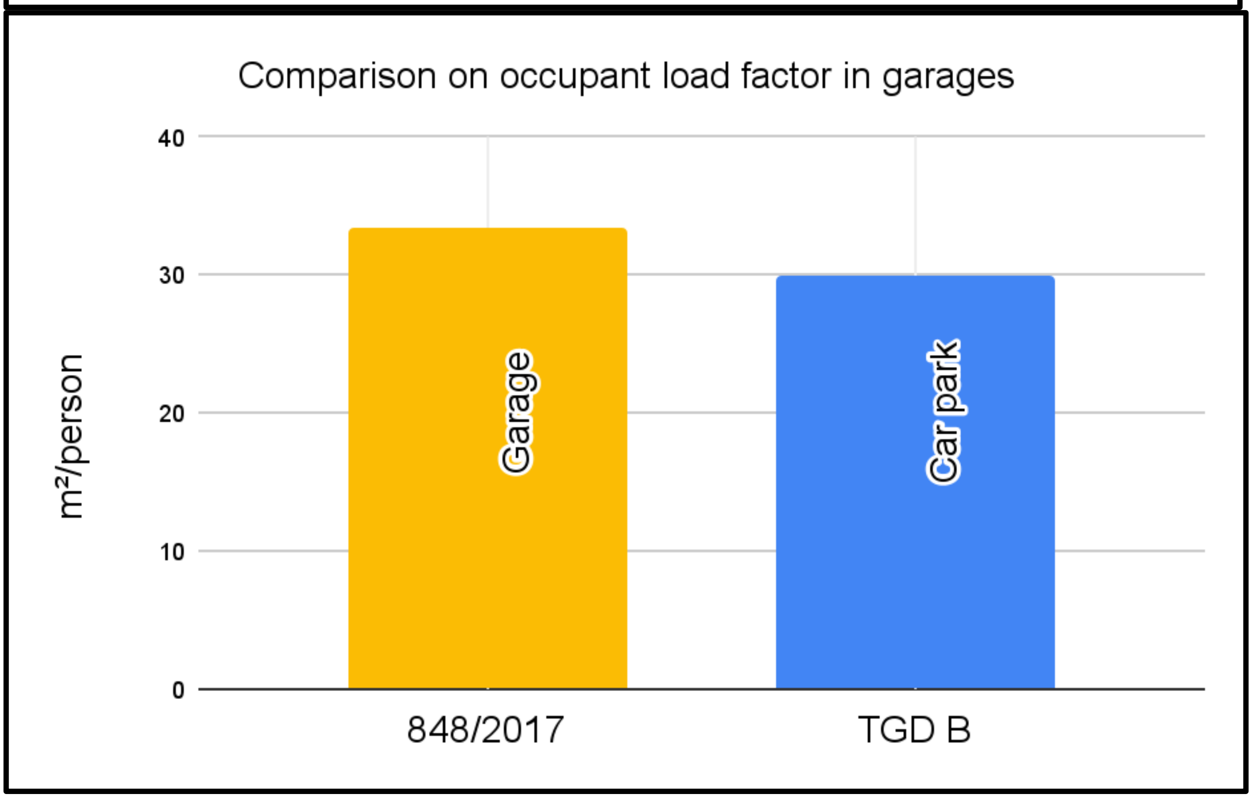
D.M.
D.M.
D.M.
D.M.


Comparison on occupant load factor in Production and Storage buildings
m²/person
40
30
20
10
0
Production and storage
Factory production area
Storage and warehouse
Factory production area
Storage and warehouse
848/2017
ADB
ADB
TGD B
TGD B


Comparison on occupant load factor in garages
m²/person
40
30
20
10
0
Garage
Car park
848/2017
TGD B

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	214		
Route choice: Locally quickest path	2	192.5	203.3	5.29
	3	197.5	201.3	0.95
Physical dist: No	4	194.5	199.6	0.86
	5	211.3	202.0	1.16
	6	199.5	201.6	0.20
	7	215	203.5	0.94

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	199.8		
Route choice: Locally quickest path	2	199.3	199.6	0.13
	3	191.5	196.9	1.36
Physical dist: No	4	189.8	195.1	0.91
	5	205	197.1	1.00
	6	191.8	196.2	0.45

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	193.5		
Route choice: Locally quickest path	2	172.3	182.9	5.79
	3	182.3	182.7	0.11
Physical dist: No	4	160	177.0	3.21
	5	179.5	177.5	0.28
	6	160	174.6	1.67
	7	163.8	173.0	0.89

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2	1	202		
Route choice: Locally quickest path	2	191.5	196.8	2.67
	3	156.8	183.4	7.26
Physical dist: No	4	169.8	180.0	1.89
	5	172.8	178.6	0.81
	6	197	181.7	1.69
	7	153.8	177.7	2.24
	8	176.8	177.6	0.06

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	316.5		
Route choice: Locally quickest path	2	321	318.8	0.71
	3	287.8	308.4	3.34
Physical dist: No	4	362.3	321.9	4.18
	5	317.3	321.0	0.29
	6	310.5	319.2	0.55

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	208.3		
Route choice: Locally quickest path	2	213.8	211.1	1.30
	3	206.5	209.5	0.72
Physical dist: Yes	4	219.8	212.1	1.21
	5	204	210.5	0.77
	6	202.5	209.2	0.64

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2 Route choice: Locally quickest path	1	210.8		
	2	203.3	207.0	1.81
	3	196.8	203.6	1.68
Physical dist: Yes	4	204.8	203.9	0.14
	5	195.5	202.2	0.83
	6	217	204.7	1.20

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2 Route choice: Locally quickest path	1	149.5		
	2	151.5	150.5	0.66
	3	157.3	152.8	1.48
Physical dist: Yes	4	163.5	155.5	1.73
	5	165.5	157.5	1.28
	6	168.5	159.3	1.16

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2 Route choice: Locally quickest path Physical dist: Yes	1	177.3		
	2	142.8	160.0	10.78
	3	157	159.0	0.64
	4	160.5	159.4	0.23
	5	166.5	160.8	0.88
	6	147.5	158.6	1.40
	7	168,3	160.0	0,87

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2 Route choice: Locally quickest path Physical dist: Yes	1	386		
	2	355.8	370.9	4.07
	3	337.5	359.8	3.09
	4	344	355.8	1.11
	5	373.5	359.4	0.98
	6	380.5	362.9	0.97

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	261.3		
Route choice: 70% / 30%	2	286.3	273.8	4.57
	3	287.5	278.4	1.64
Physical dist: No	4	267.5	275.7	0.99
	5	308.8	282.3	2.35
	6	281.3	282.1	0.06

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	237		
Route choice: 70% / 30%	2	259.3	248.2	4.49
	3	256	250.8	1.04
Physical dist: No	4	280.8	258.3	2.91
	5	293	265.2	2.62
	6	248	262.4	1.09

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	193		
Route choice: 70% / 30%	2	203.3	198.2	2.60
	3	242.5	212.9	6.94
Physical dist: No	4	204.5	210.8	1.00
	5	237.8	216.2	2.50
	6	199.5	213.4	1.31
	7	276.3	222.4	4.04
	8	240.8	224.7	1.02

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2	1	167,8		
Route choice: 70% / 30%	2	216,5	192,2	12,67
	3	180,3	188,2	2,1
Physical dist: No	4	215,3	195.0	3,47
	5	203,3	196,6	0,85
	6	187,5	195,1	0,78
	7	226,3	199,6	2,23

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	479.5		
Route choice: 70% / 30%	2	497.3	488.4	1.82
	3	491.8	489.5	0.23
Physical dist: No	4	476	486.2	0.70
	5	495	487.9	0.36
	6	486.5	487.7	0.05

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	270,8		
Route choice: 70% / 30%	2	289,3	280,1	3,30
	3	292,5	284,2	1,46
Physical dist: No	4	308,3	290,2	2,08
	5	280,8	288,3	0,65
	6	282,3	287,3	0,35
	7	277,8	288,5	0,40

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	272.3		
Route choice: 70% / 30%	2	274.3	273.3	0.36
	3	275.3	274.0	0.24
Physical dist:	4	274	275.9	0.003

Yes	5	282	275.6	0.58
	6	274.5	275.4	0.07

Appendix 2 (8/17) Convergence study

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	216,3		
Route choice: 70% / 30%	2	295,5	255,9	15,47
	3	204,8	238,9	7,13
Physical dist: Yes	4	236,3	238,2	0,27
	5	213,5	233,3	2,12
	6	201,5	227,9	2,32
	7	192,8	222,9	2,25
	8	250	226,3	1,49

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2	1	192,8		
Route choice: 70% / 30%	2	190,3	191.6	0.65
	3	179,5	187.5	2.14
Physical dist: Yes	4	228,3	197.7	5.15
	5	251	208.4	5.11
	6	261	217.2	4.04
	7	257,3	222.9	2.57
	8	217,3	222.2	0.31

	9	220	221.9	0.11
	10	246,5	224.4	1.09

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	548.5		
Route choice: 70% / 30%	2	533	540.8	1.43
	3	570	550.5	1.77
Physical dist: Yes	4	558	552.4	0.34
	5	557.8	553.5	0.20
	6	528.3	549.3	0.76

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	211.3		
Route choice: Go to closest exit	2	219.5	215.4	1.90
	3	213	214.6	0.37
Physical dist: No	4	217.3	215.3	0.31
	5	232.3	218.7	1.56
	6	202	215.9	1.29

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	197,5		
Route choice: Go to closest exit	2	203	200,3	1,37
	3	197,8	199,4	0,41
Physical dist: No	4	189,8	197,0	1,22

	5	183	194,2	1,44
	6	201	195,4	0,58

Appendix 2 (10/17) Convergence study

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	182.3		
Route choice: Go to closest exit	2	168.5	175.4	3.93
	3	189.5	180.1	2.61
Physical dist: No	4	176.3	179.2	0.53
	5	181.5	179.6	0.26
	6	164.3	177.1	1.44

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2	1	182.3		
Route choice: Go to closest exit	2	170.0	176.1	3.49
	3	143.8	165.4	6.52
Physical dist: No	4	174.0	167.5	1.29
	5	154.5	164.9	1.58
	6	149.3	162.3	1.60
	7	166.5	162.9	0.37
	8	171.8	164.0	0.68

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	387.5		
Route choice: Go to closest exit	2	418.3	402.9	3,82
	3	465.3	423.7	4,91
Physical dist: No	4	420	422.8	0,22
	5	458	429.8	1,64
	6	461.5	435.1	1,21

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	210.0		
Route choice: Go to closest exit	2	217.5	213.8	1.75
	3	210.8	212.8	0.46
Physical dist: Yes	4	211.0	212.3	0.21
	5	222.3	214.3	0.93
	6	213.3	214.2	0.08

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	217.5		
Route choice: Go to closest exit	2	210.8	214.2	1.56
	3	195.8	208.0	2.94
Physical dist:	4	234.8	214.7	3.12

Yes	5	211.5	214.1	0.30
	6	204.3	212.5	0.77

Appendix 2 (12/17) Convergence study

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	178.0		
Route choice: Go to closest exit	2	191.5	184.8	3.65
	3	164.8	178.1	3.73
Physical dist: Yes	4	190.8	181.3	1.75
	5	185.3	182.1	0.44
	6	162.3	178.8	1.84

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	179.5		
Route choice: Go to closest exit	2	200.8	190.2	5.60
	3	188.3	189.5	0.32
Physical dist: Yes	4	166.5	183.8	3.13
	5	189.5	184.9	0.62
	6	159.8	180.7	2.32
	7	199.3	183.4	1.45

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	522.8		
Route choice: Go to closest exit	2	498	510.4	2.43
	3	506.5	509.1	0.26
Physical dist: Yes	4	478.8	501.5	1.51
	5	481.5	497.5	0.80
	6	474.8	493.7	0.77

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	363.5		
Route choice: Go to main exit	2	331.8	347.65	4.56
	3	340.5	345.27	0.69
Physical dist: No	4	336.5	343.08	0.64
	5	350.3	344.52	0.42
	6	357.5	346.68	0.62

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	355.0		
Route choice: Go to main exit	2	358.5	356.8	0.49
	3	328.8	347.4	2.68
Physical dist: No	4	333.0	343.8	1.05
	5	357.0	346.5	0.76

	6	323.0	342.6	1.14

Appendix 2 (14/17) Convergence study

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	244.3		
Route choice: Go to main exit	2	261	252.7	3.30
	3	257.3	254.2	0.61
Physical dist: No	4	233.5	249.0	2.08
	5	242.8	247.8	0.50
	6	247	247.7	0.05

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2	1	243.8		
Route choice: Go to main exit	2	194.5	219.2	11.25
	3	255.8	231.4	5.28
Physical dist: No	4	244.8	225.2	2.76
	5	263.5	231.7	2.83
	6	211.5	239.7	3.32
	7	295.5	234.0	2.41
	8	235.5	244.3	4.19

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2	1	711.3		
Route choice: Go to main exit	2	718.8	715.1	0.52
	3	693.3	707.8	1.02
Physical dist: No	4	727.3	712.7	0.68
	5	687	707.5	0.73
	6	687.8	704.3	0.47

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	360		
Route choice: Go to main exit	2	353.5	356.8	0.91
	3	394.5	369.3	3.41
Physical dist: Yes	4	372.8	370.2	0.23
	5	357.7	367.7	0.68
	6	378.8	369.6	0.50

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.112 p/m^2	1	361.8		
Route choice: Go to main exit	2	349.3	355.6	1.76
	3	346	352.4	0.90
Physical dist: Yes	4	362	354.8	0.68
	5	342	352.2	0.73

	6	342.8	350.7	0.45

Appendix 2 (16/17) Convergence study

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.0227 p/m^2	1	211.3		
Route choice: Go to main exit	2	220.3	215.8	2.09
	3	255	228.9	5.71
Physical dist: Yes	4	233.8	230.1	0.54
	5	284.8	241	4.54
	6	331.8	256.2	5.91
	7	234	253	1.25
	8	237.5	251	0.77
	9	313.3	258	2.68
	10	218	254	1.57
	11	225.3	251.4	1.04

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.013 p/m^2 Route choice: Go to main exit Physical dist: Yes	1	360		
	2	268.5	314.3	14.56
	3	253	293.8	6.95
	4	242.5	281	4.57
	5	212	267.2	5.16
	6	238.5	262.4	1.82
	7	271.3	263.7	0.48
	8	305.8	269.0	1.96
	9	219.8	263.5	2.07
	10	251.3	262.3	0.46

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.4 p/m^2 Route choice: Go to main exit Physical dist: Yes	1	833		
	2	790.8	811.9	2.60
	3	768.5	797.4	1.81
	4	820.3	803.2	0.71
	5	865.5	815.6	1.53
	6	794.3	812.1	0.44

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	306		
Route choice: Locally quickest path	2	305.3	305.7	0.1 %
	3	296.5	302.6	1.0 %
Physical dist: No	4	290	299.5	1.1 %
Door width: 20%	5	307.3	301	0.5 %
	6	309.8	302.5	0.5 %

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	375		
Route choice: Locally quickest path	2	366	370.5	1.2 %
	3	369.5	367.8	0.7 %
Physical dist: No	4	358	363.8	1.1 %
Door width: 15%	5	335	346.5	5.0 %
	6	371.8	353.4	2.0 %

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	455.3		
Route choice: 70/30	2	478.3	466.8	2.5 %
	3	470.3	467	0.2 %
Physical dist: No	4	486.3	472.6	1.0 %
Door width: 25%	5	480.3	474.1	0.3 %
	6	461.8	472.1	0.4 %

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	537		
Route choice: 70/30	2	565.5	551.3	2.6 %
	3	572	558.2	1.2 %
Physical dist: No	4	550.3	556.2	0.4 %
Door width: 20%	5	530.8	551.1	0.9 %
	6	580.8	556.1	0.9 %

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	435.5		
Route choice: Go to closest	2	382.8	409.2	6.4 %
	3	371.8	396.7	3.1 %
Physical dist: No	4	345.5	383.9	3.3 %
Door width: 20%	5	422	391.5	1.9 %
	6	410	394.6	0.8 %

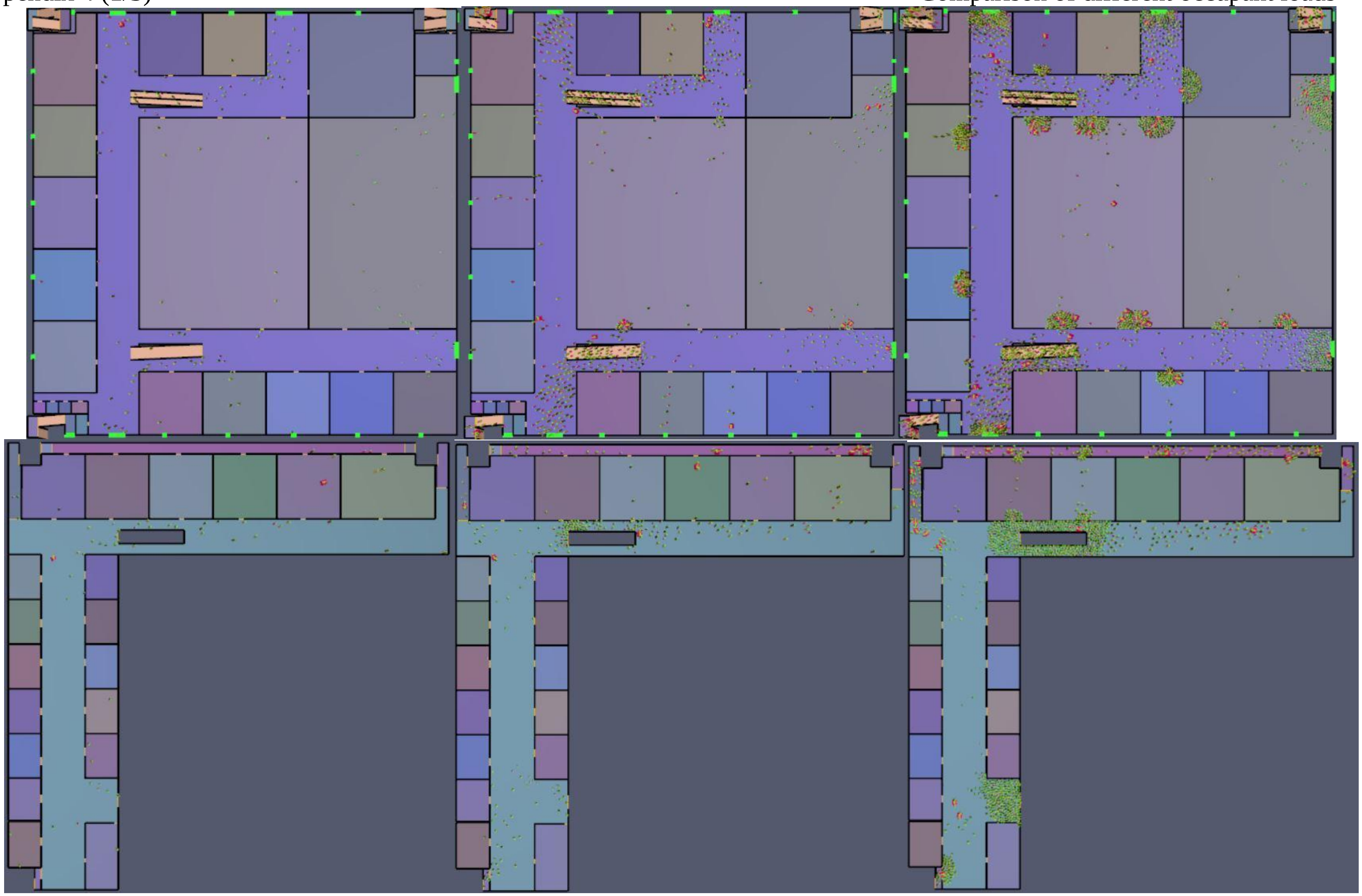
Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	445.8		
Route choice: Go to closest	2	450.3	448.2	0.5 %
	3	498.3	464.8	3.6 %
Physical dist: No	4	451.3	461.4	0.7 %
Door width: 15%	5	441	457.3	0.9 %

	6	507.8	465.8	1.8 %

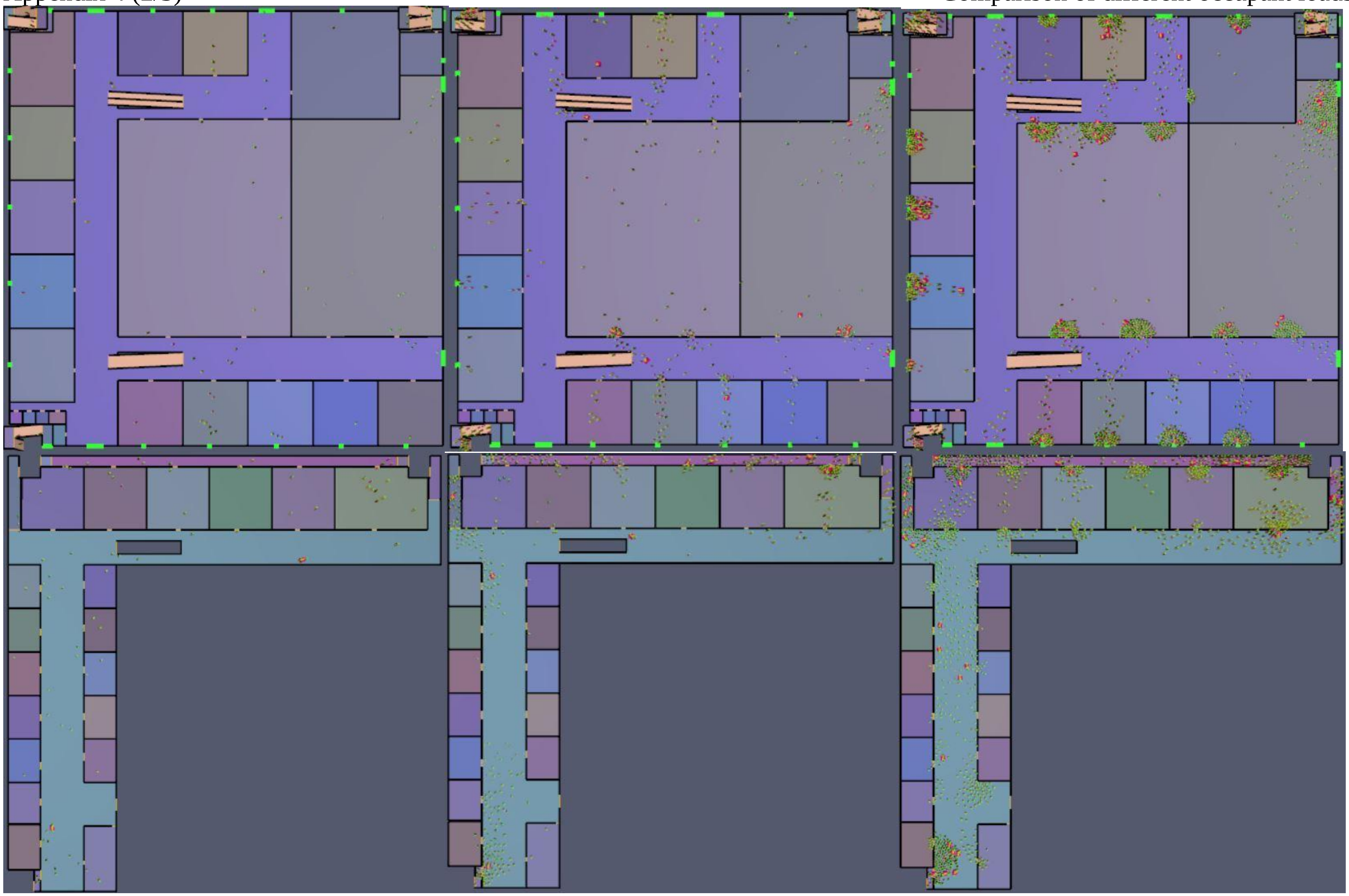
Appendix 3 (3/3) Convergence study - Reduced Door Width

Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	690,5		
Route choice: Go to main	2	690	690,25	0,0 %
	3	680,5	687	0,5 %
Physical dist: No	4	652,5	678,375	1,3 %
Door width: 15%	5	651,8	673,06	0,8 %
	6	671,3	672,76667	0,0 %

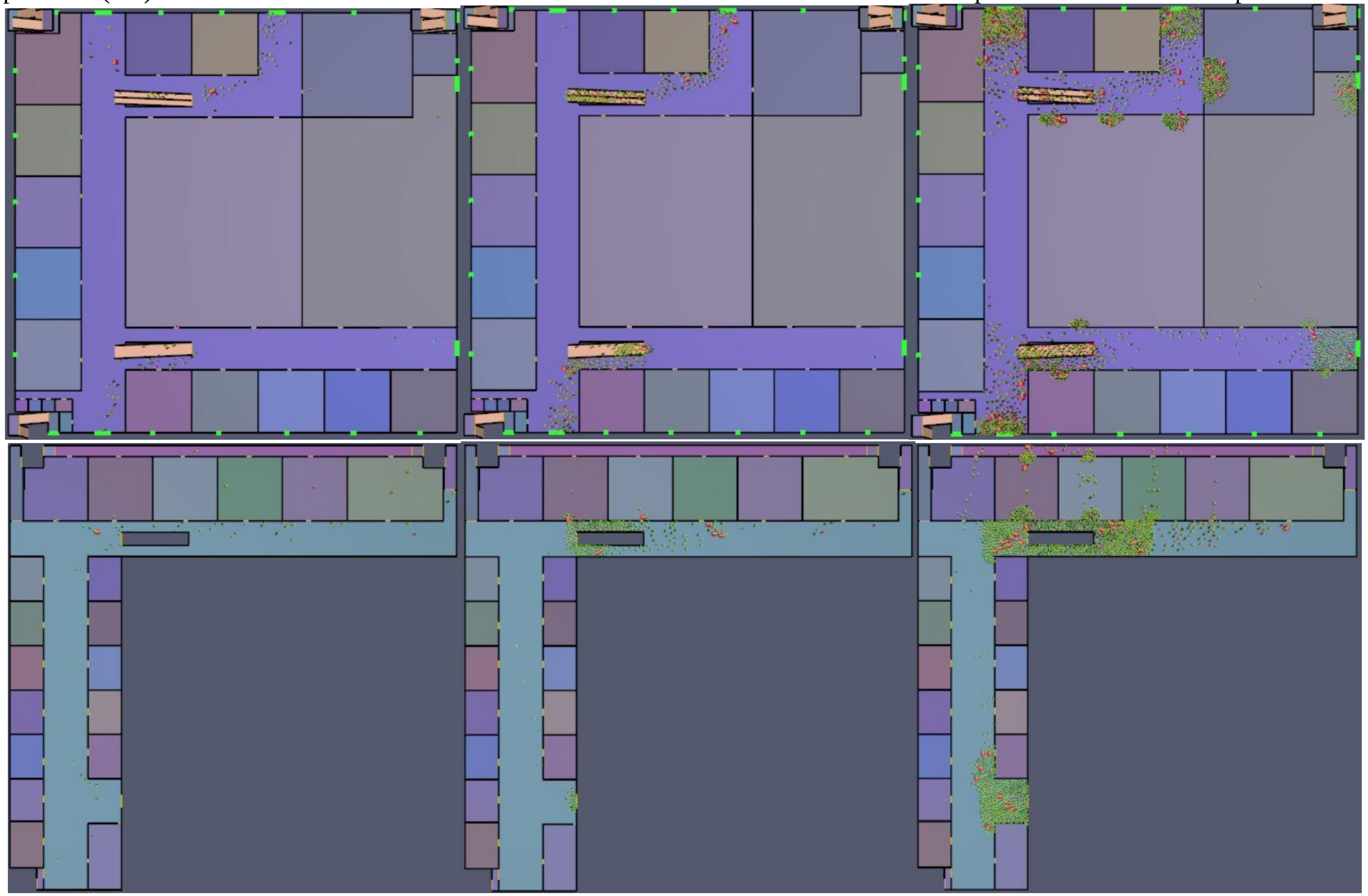
Scenario:	Run number	RSET (s)	Average RSET(s)	Convergence (%)
OD: 0.125 p/m^2	1	704.8		
Route choice: Go to main	2	723.8	714.3	1.3 %
	3	697.3	708.6	0.8 %
Physical dist: No	4	723.5	712.4	0.5 %
Door width: 14%	5	699.3	709.7	0.4 %
	6	692	706.8	0.4 %



Occupant load: 0.0227/0.125/0.4 person/m^2, Route choice: 70/30, Physical distancing: No

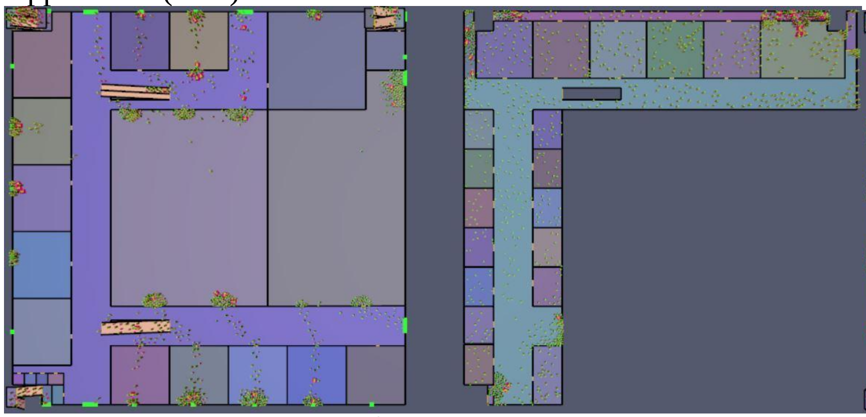


Occupant load: 0.0227/0.125/0.4 person/m^2, Route choice: Go to closest, Physical distancing: No

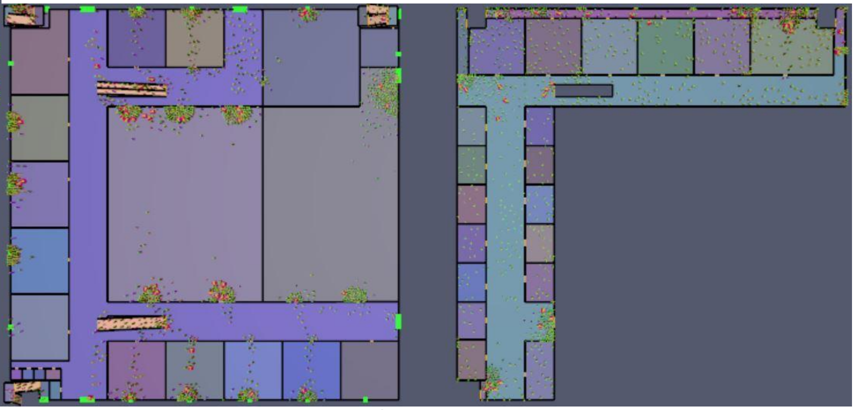


Occupant load: 0.0227/0.125/0.4 person/m^2, Route choice: Go to main, Physical distancing: No

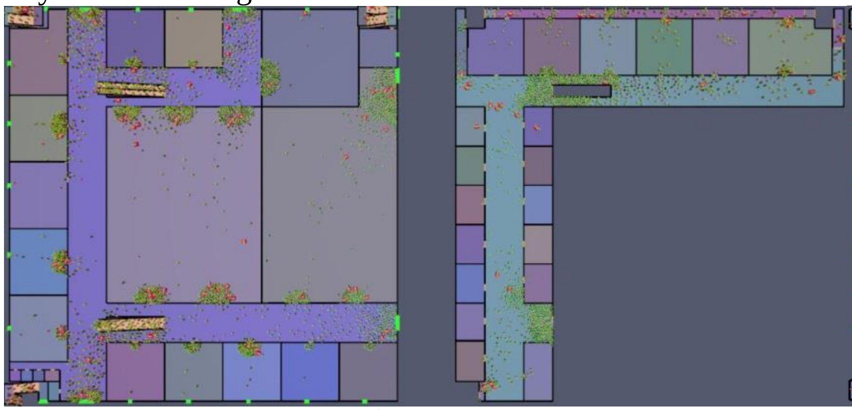
Appendix 5 (1/10) How the crowd is formed with or without physical distancing



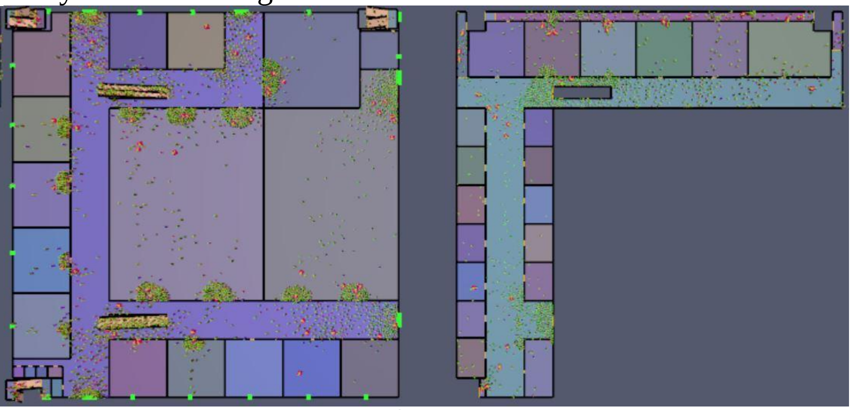
Occupant load: 0.4 person/m^2
Route choice: Locally quickest path
Physical distancing: No



Occupant load: 0.4 person/m^2
Route choice: Locally quickest path
Physical distancing: No

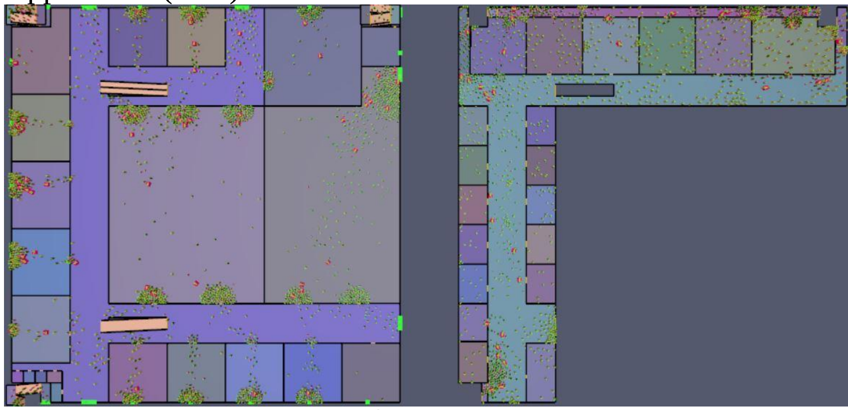


Occupant load: 0.4 person/m^2
Route choice: 70/30
Physical distancing: No

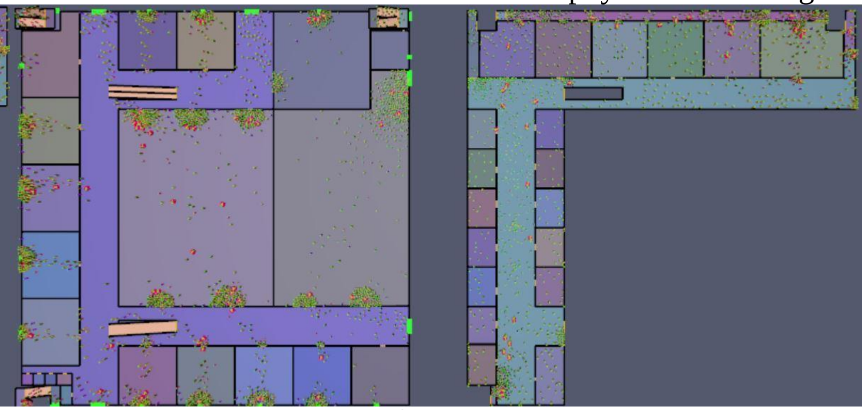


Occupant load: 0.4 person/m^2
Route choice: 70/30
Physical distancing: No

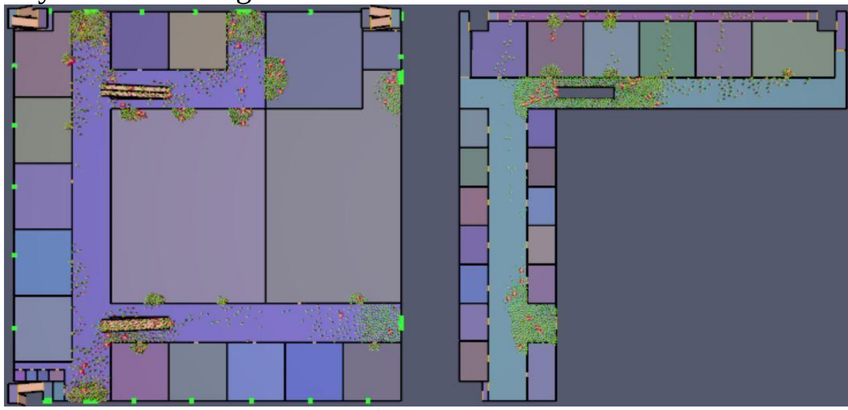
Appendix 5 (2/10) How the crowd is formed with or without physical distancing



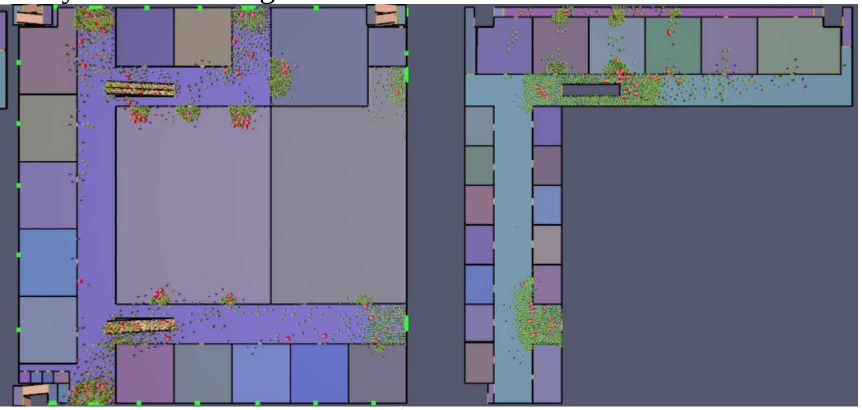
Occupant load: 0.4 person/m^2
Route choice: Go to closest
Physical distancing: No



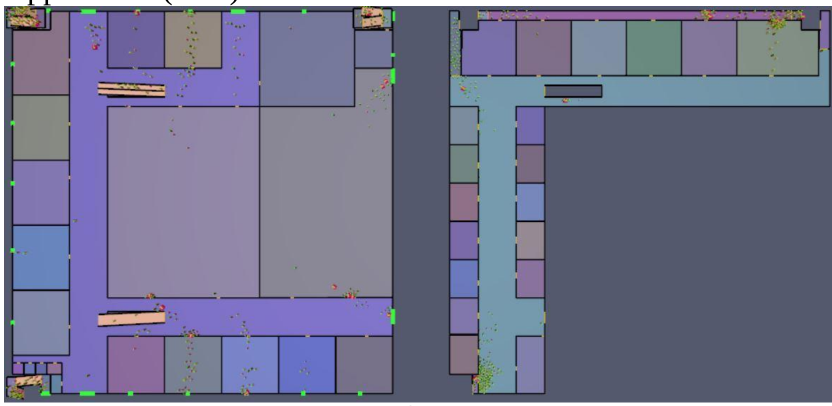
Occupant load: 0.4 person/m^2
Route choice: Go to closest
Physical distancing: Yes



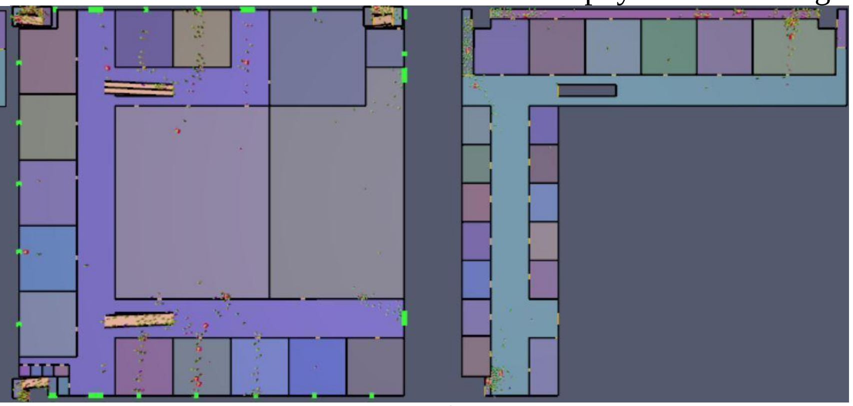
Occupant load: 0.4 person/m^2
Route choice: Go to main
Physical distancing: No



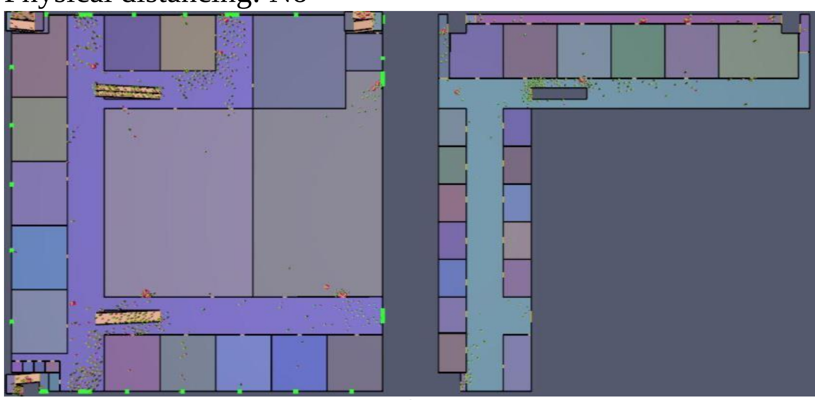
Occupant load: 0.4 person/m^2
Route choice: Go to main
Physical distancing: Yes



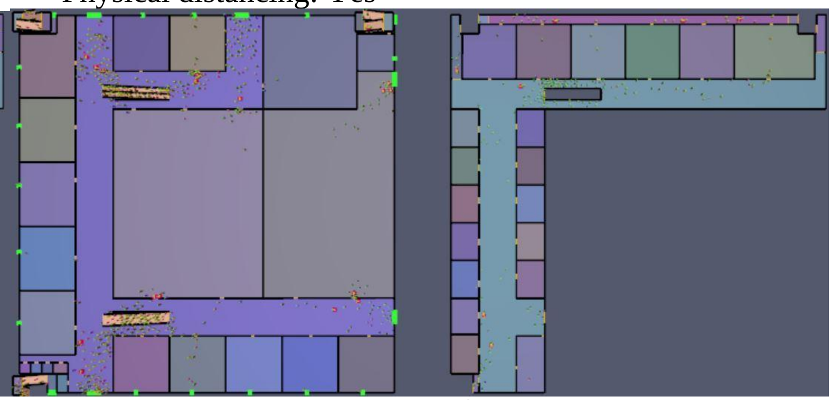
Occupant load: 0.125 person/m^2
Route choice: Locally quickest path
Physical distancing: No



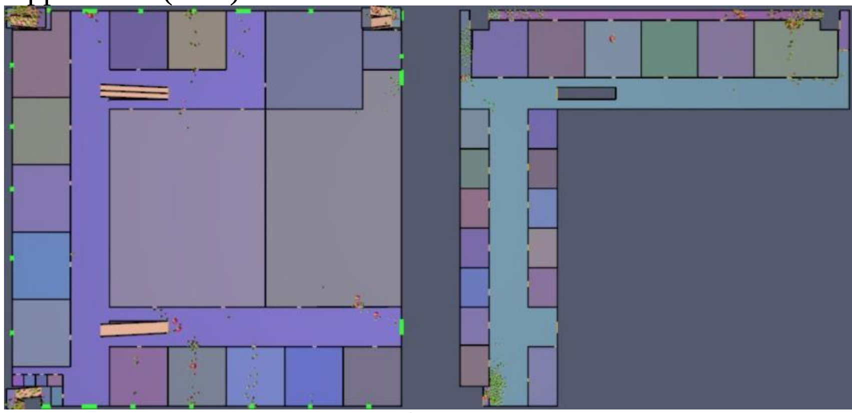
Occupant load: 0.125 person/m^2
Route choice: Locally quickest path
Physical distancing: Yes



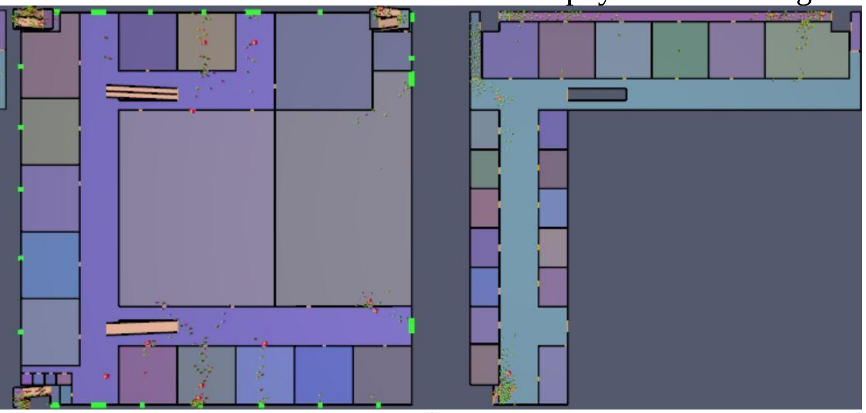
Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No



Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: Yes

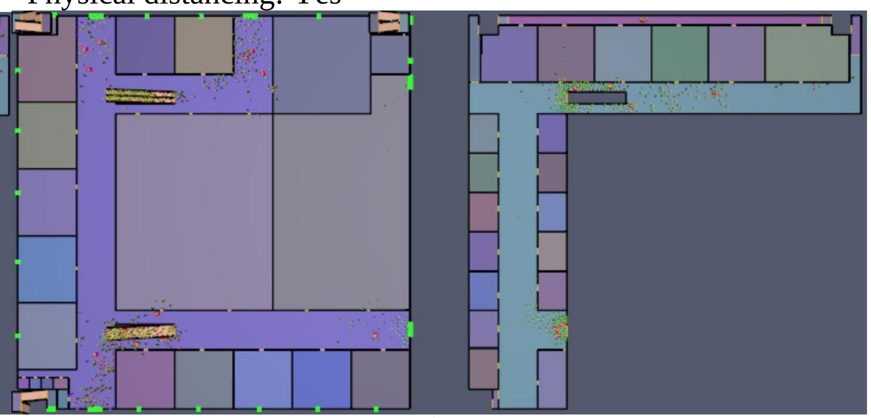


Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No



Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: Yes

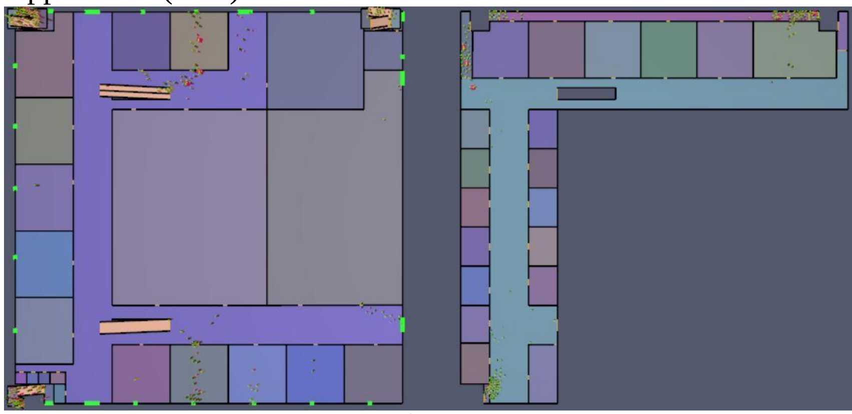
Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No



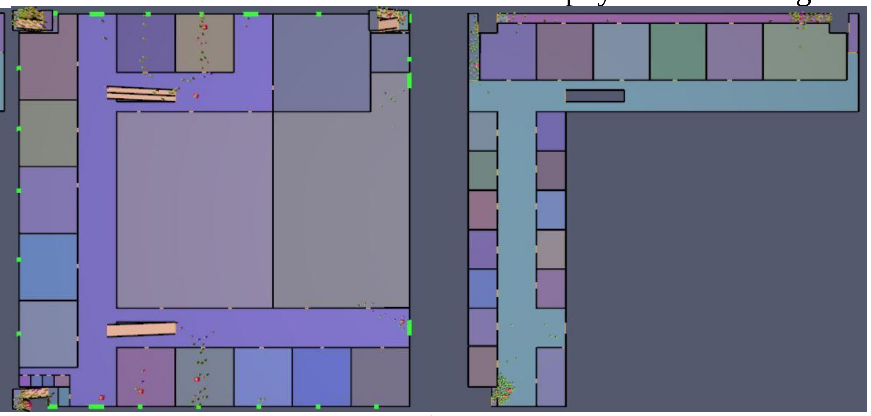
Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: Yes

Appendix 5 (5/10)

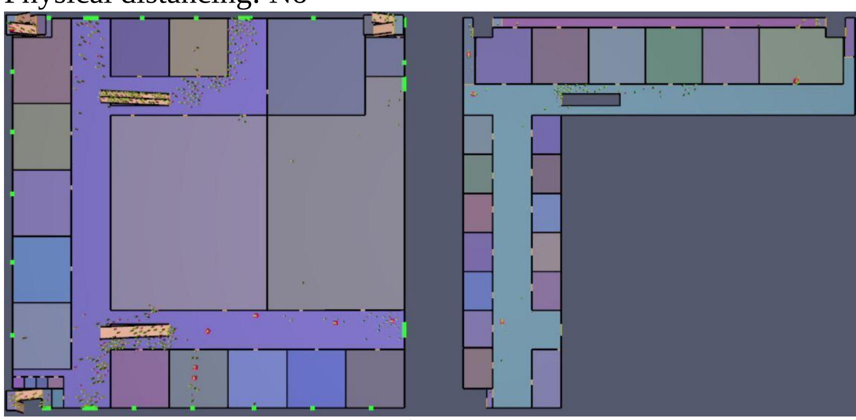
How the crowd is formed with or without physical distancing



Occupant load: 0.112 person/m^2
Route choice: Locally quickest path
Physical distancing: No



Occupant load: 0.112 person/m^2
Route choice: Locally quickest path
Physical distancing: Yes

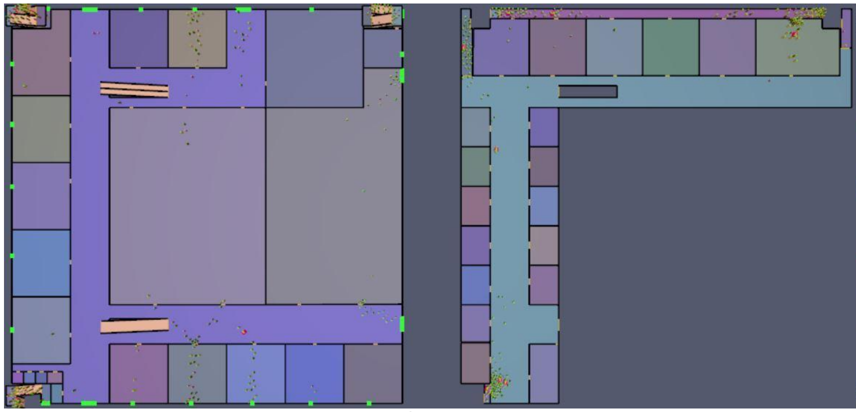


Occupant load: 0.112 person/m^2
Route choice: 70/30
Physical distancing: No

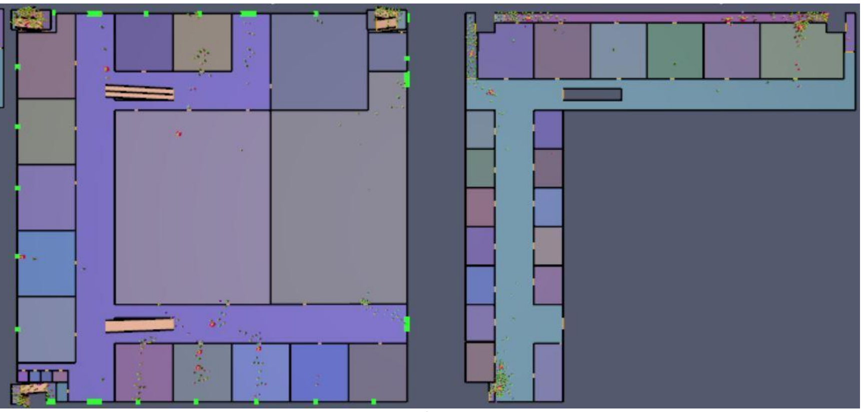
Occupant load: 0.112 person/m^2
Route choice: 70/30
Physical distancing: Yes

Appendix 5 (6/10)

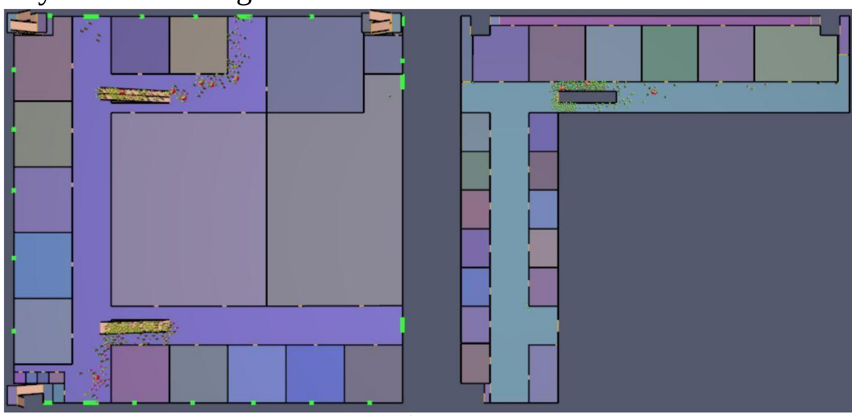
How the crowd is formed with or without physical distancing



Occupant load: 0.112 person/m^2
Route choice: Go to closest
Physical distancing: No

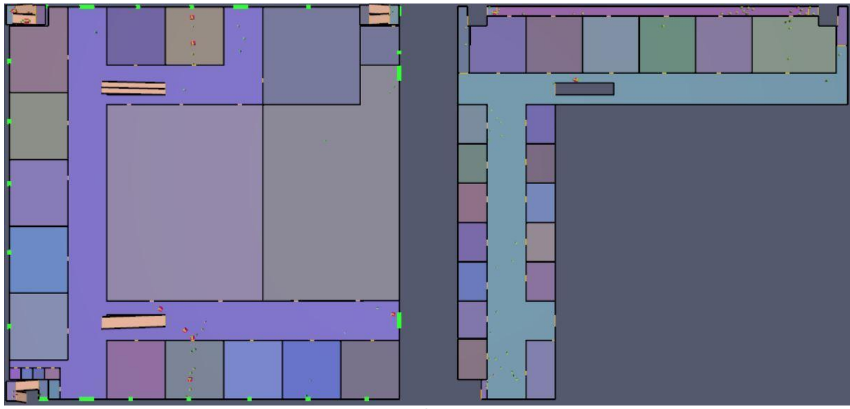


Occupant load: 0.112 person/m^2
Route choice: Go to closest
Physical distancing: Yes

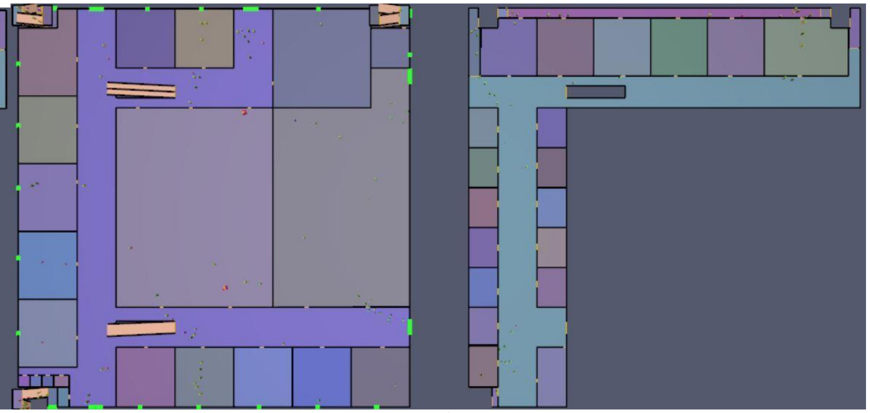


Occupant load: 0.112 person/m^2
Route choice: Go to main
Physical distancing: No

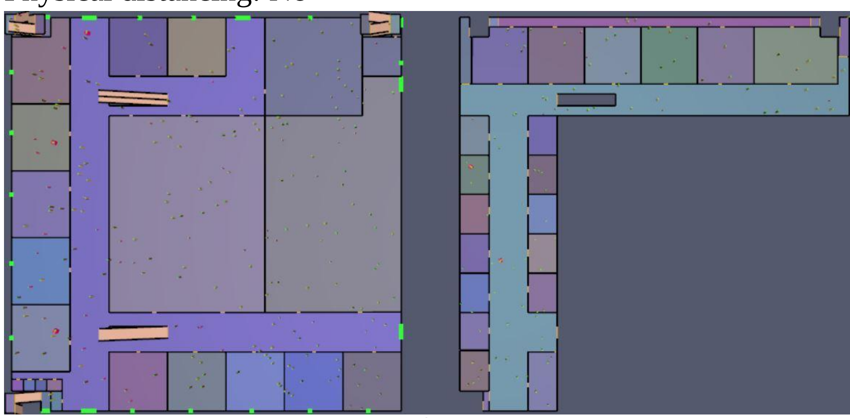
Occupant load: 0.112 person/m^2
Route choice: Go to main
Physical distancing: Yes



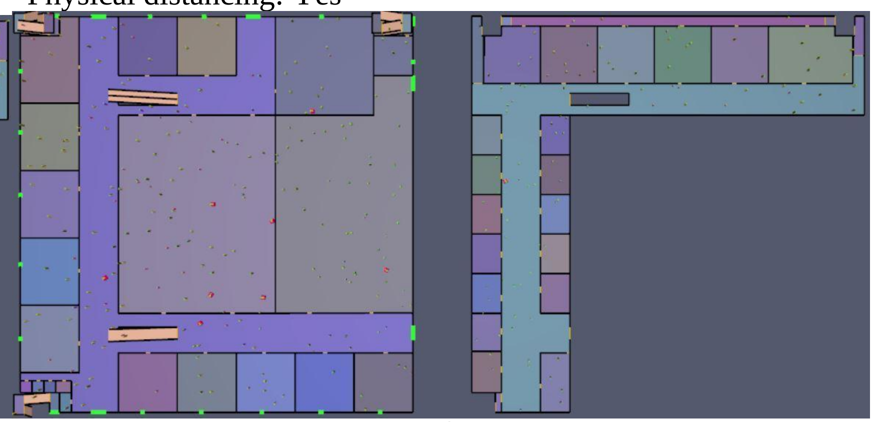
Occupant load: 0.0227 person/m^2
Route choice: Locally quickest path
Physical distancing: No



Occupant load: 0.0227 person/m^2
Route choice: Locally quickest path
Physical distancing: Yes



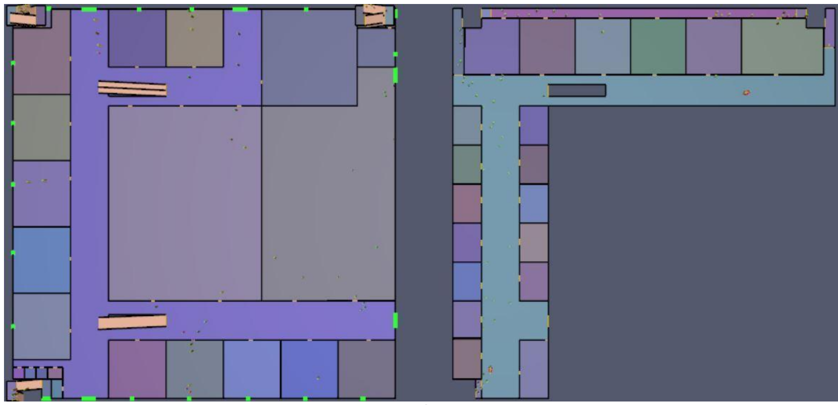
Occupant load: 0.0227 person/m^2
Route choice: 70/30
Physical distancing: No



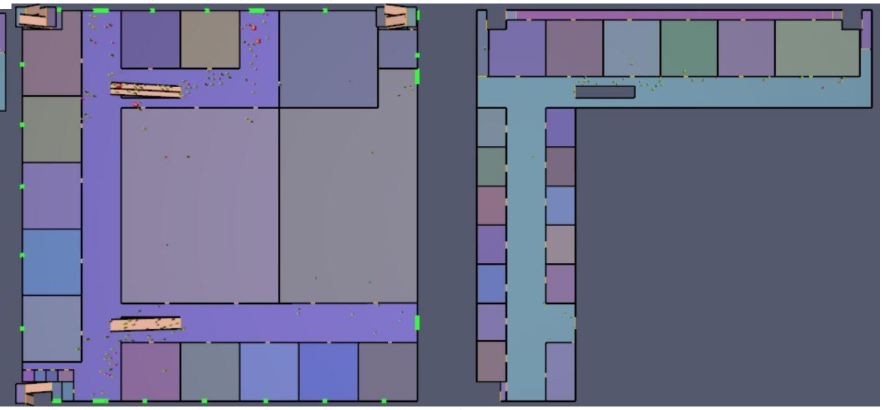
Occupant load: 0.0227 person/m^2
Route choice: 70/30
Physical distancing: Yes

Appendix 5 (8/10)

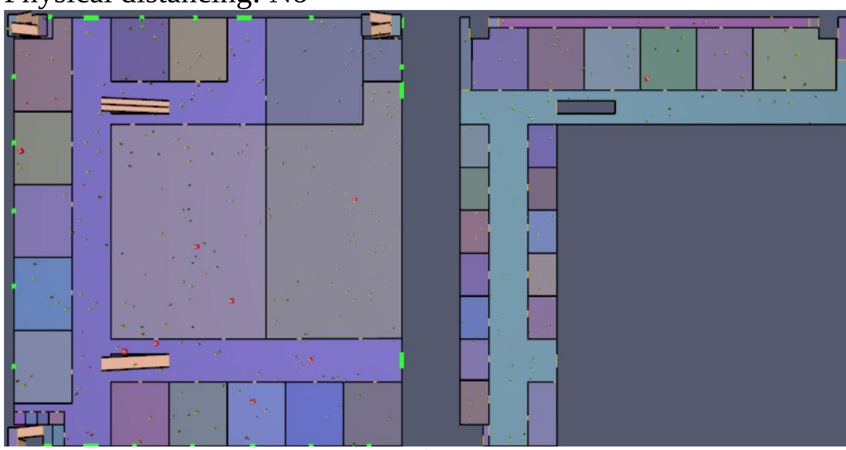
How the crowd is formed with or without physical distancing



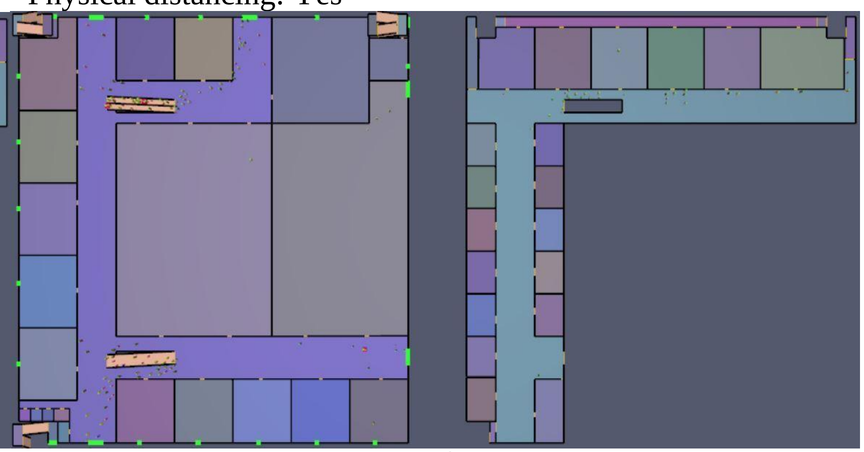
Occupant load: 0.0227 person/m^2
Route choice: Go to closest
Physical distancing: No



Occupant load: 0.0227 person/m^2
Route choice: Go to closest
Physical distancing: Yes



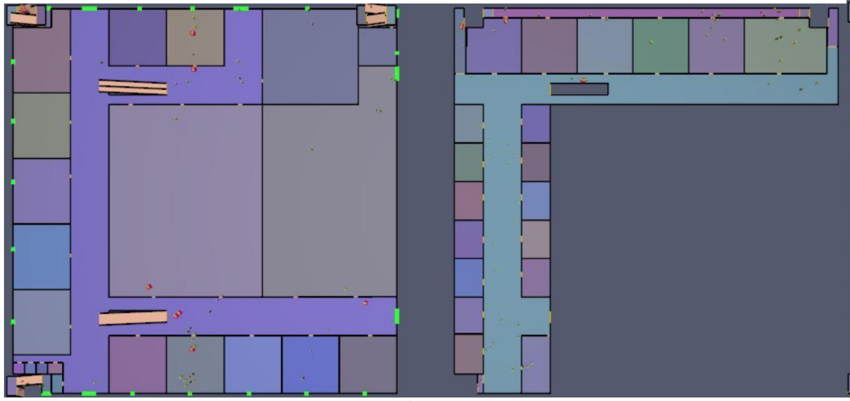
Occupant load: 0.0227 person/m^2
Route choice: Go to main
Physical distancing: No



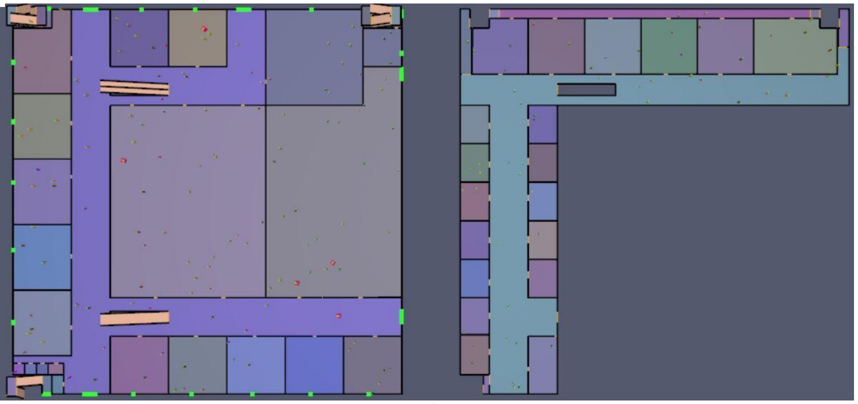
Occupant load: 0.0227 person/m^2
Route choice: Go to main
Physical distancing: Yes

Appendix 5 (9/10)

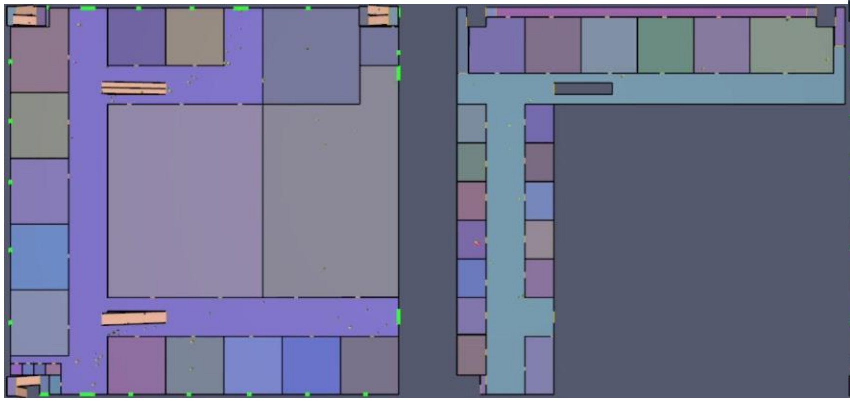
How the crowd is formed with or without physical distancing



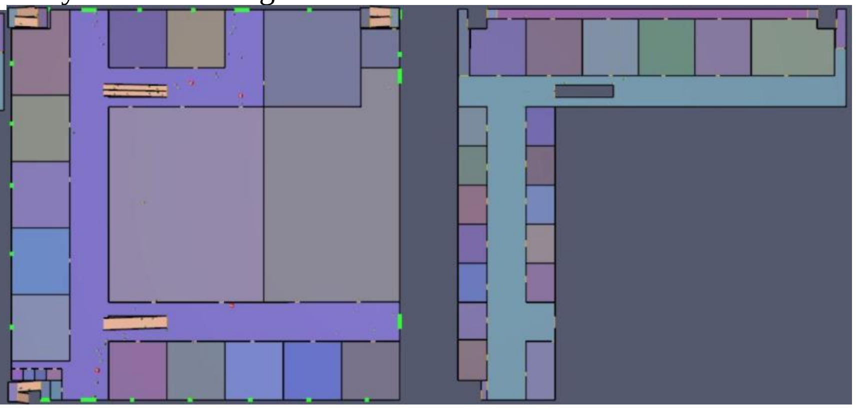
Occupant load: 0.013 person/m^2
Route choice: Locally quickest path
Physical distancing: No



Occupant load: 0.013 person/m^2
Route choice: Locally quickest path
Physical distancing: Yes



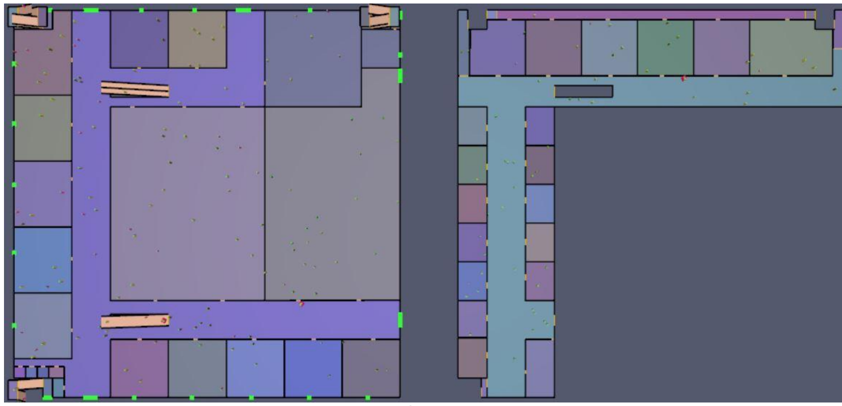
Occupant load: 0.013 person/m^2
Route choice: 70/30
Physical distancing: No



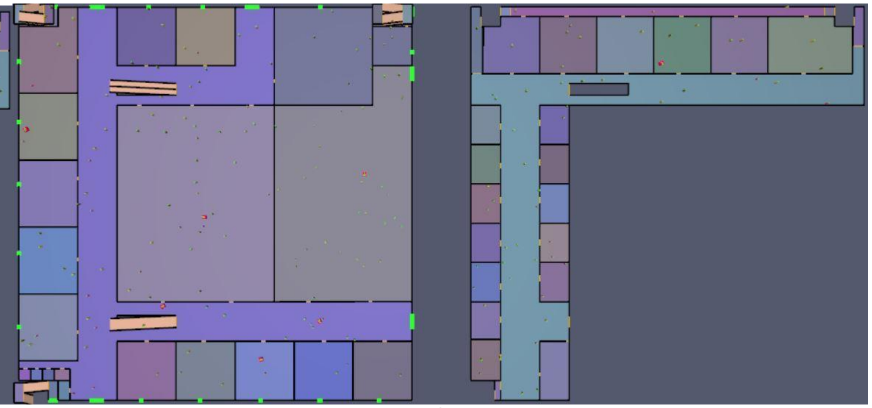
Occupant load: 0.013 person/m^2
Route choice: 70/30
Physical distancing: Yes

Appendix 5 (10/10)

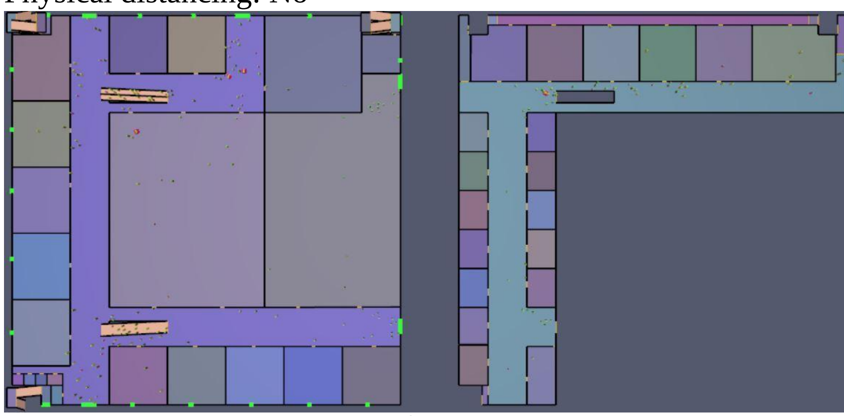
How the crowd is formed with or without physical distancing



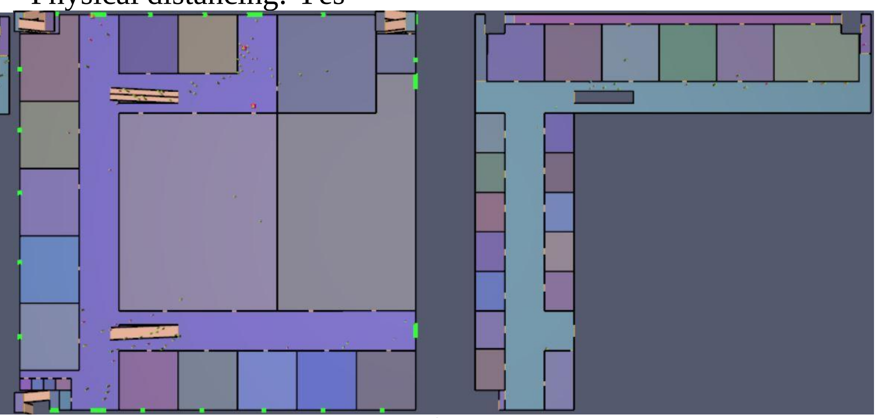
Occupant load: 0.013 person/m^2
Route choice: Go to closest
Physical distancing: No



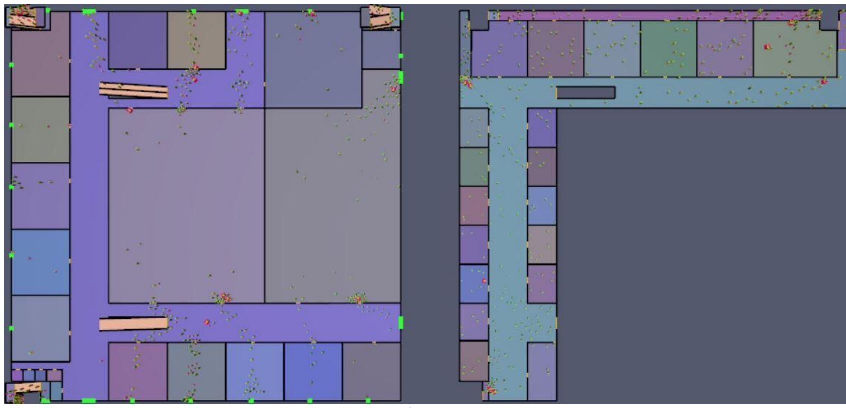
Occupant load: 0.013 person/m^2
Route choice: Go to closest
Physical distancing: Yes



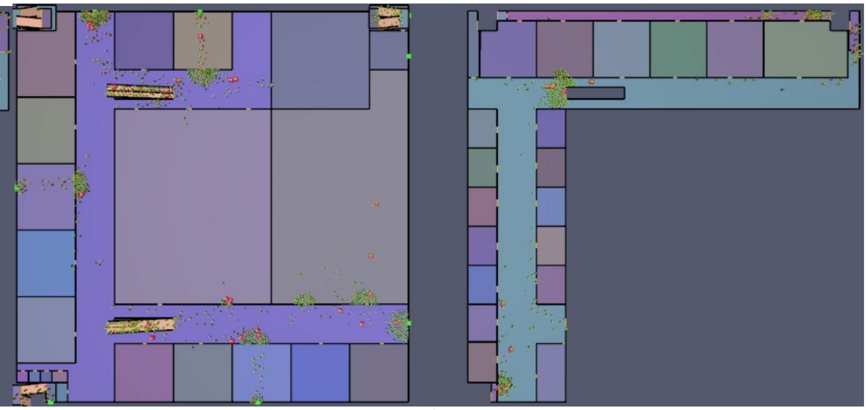
Occupant load: 0.013 person/m^2
Route choice: Go to main
Physical distancing: No



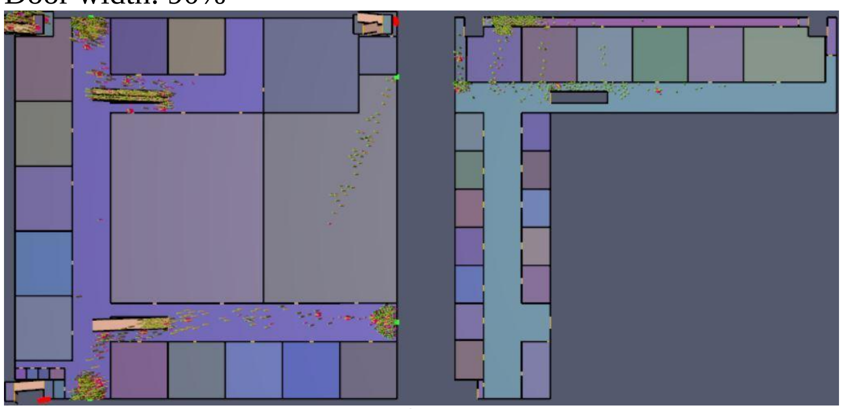
Occupant load: 0.013 person/m^2
Route choice: Go to main
Physical distancing: Yes



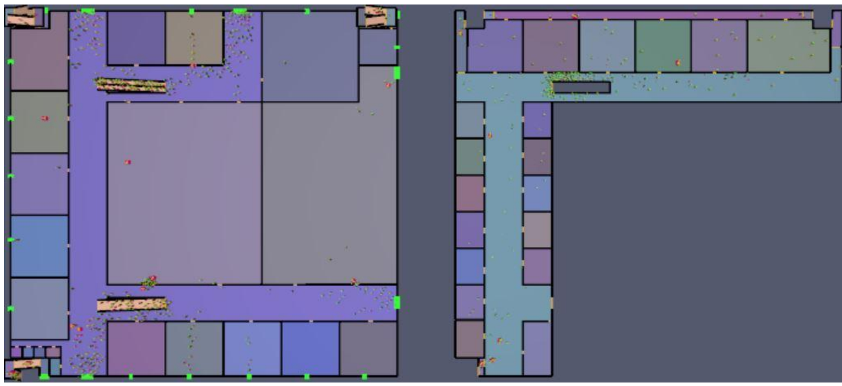
Occupant load: 0.125 person/m^2
Route choice: Locally quickest path
Physical distancing: No
Door width: 90%

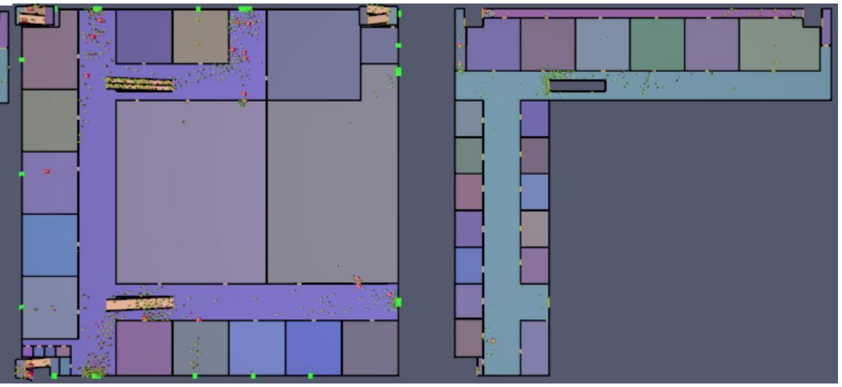


Occupant load: 0.125 person/m^2
Route choice: Locally quickest path
Physical distancing: No
Door width: 90%



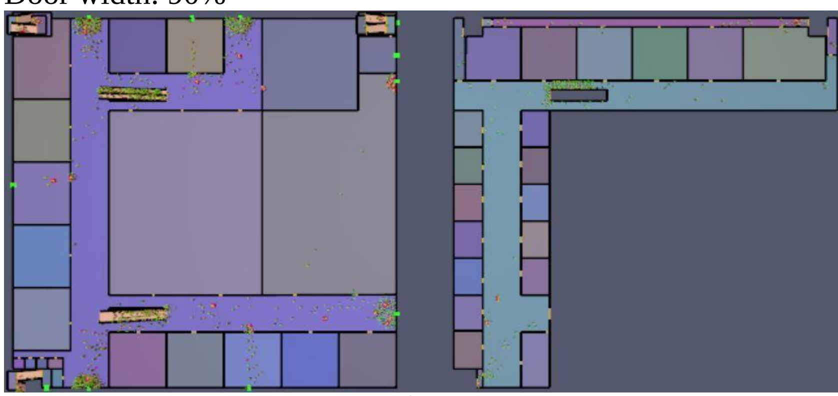
Occupant load: 0.125 person/m^2
Route choice: Locally quickest path
Physical distancing: No
Door width: 15%





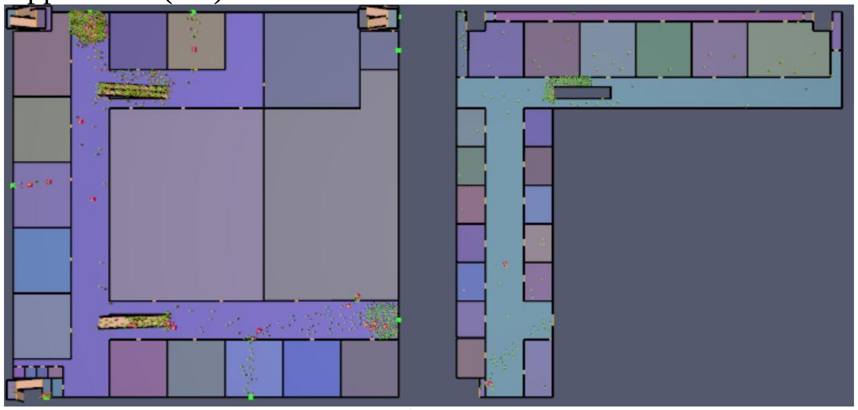
Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No
Door width: 90%

Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No
Door width: 60%

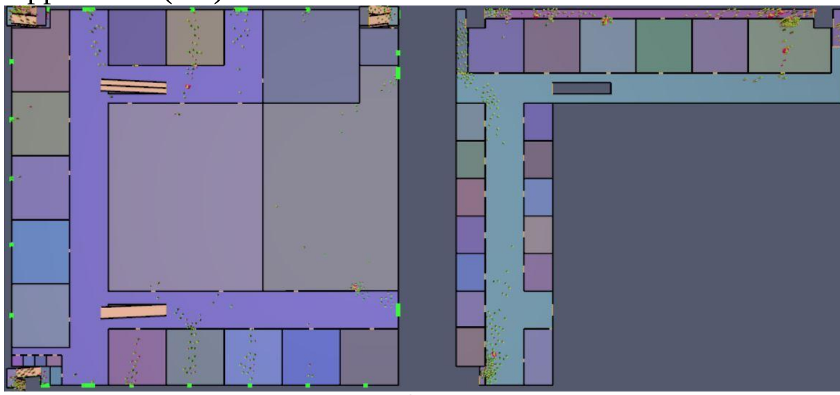


Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No
Door width: 20%

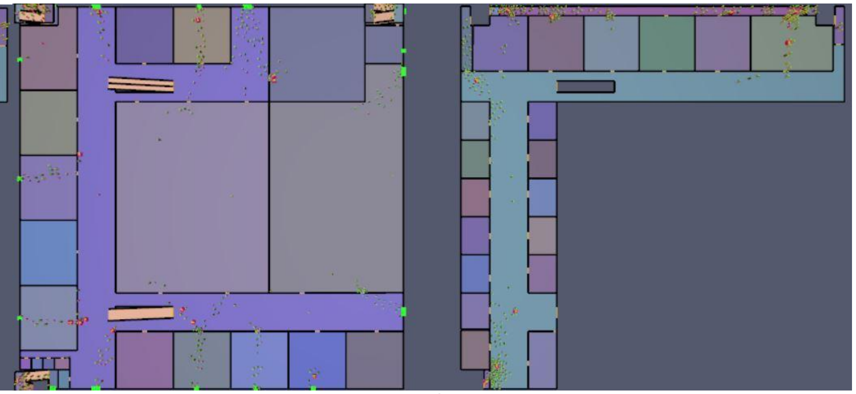
Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No
Door width: 20%



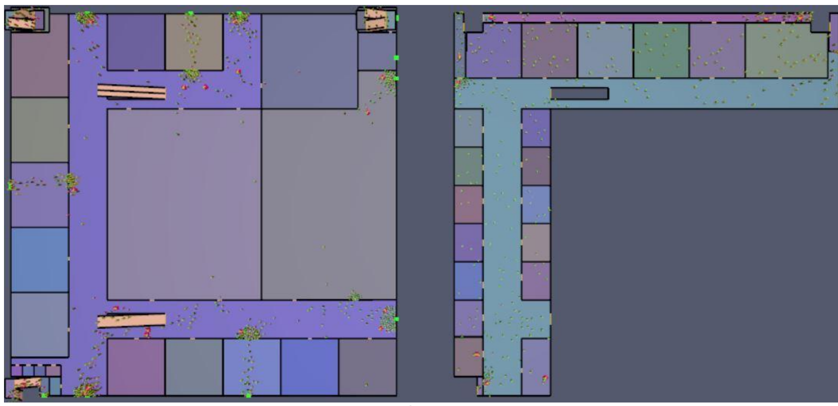
Occupant load: 0.125 person/m^2
Route choice: 70/30
Physical distancing: No
Door width: 20%



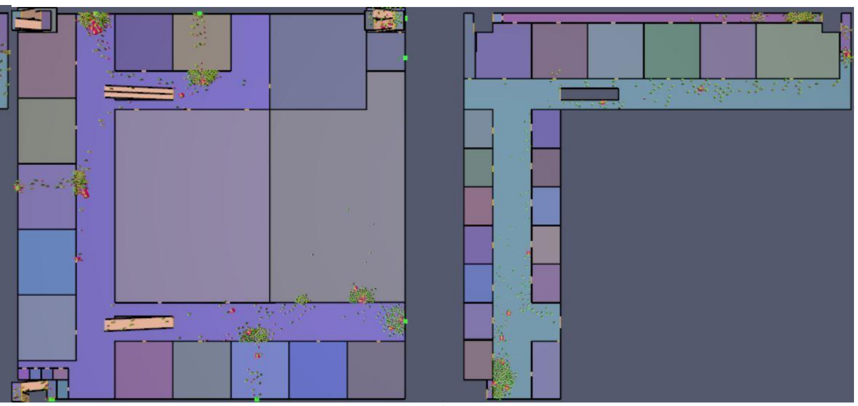
Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No
Door width: 90%



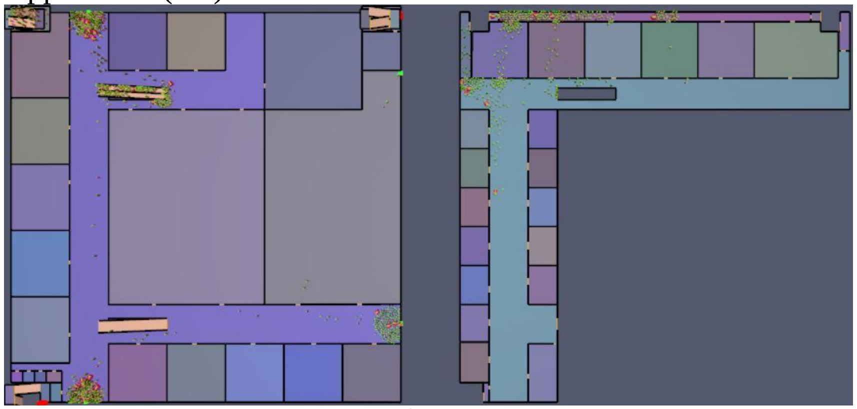
Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No
Door width: 60%



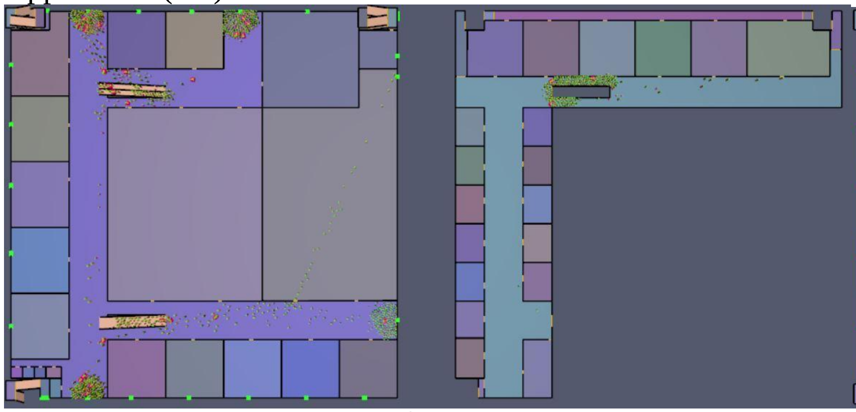
Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No
Door width: 30%



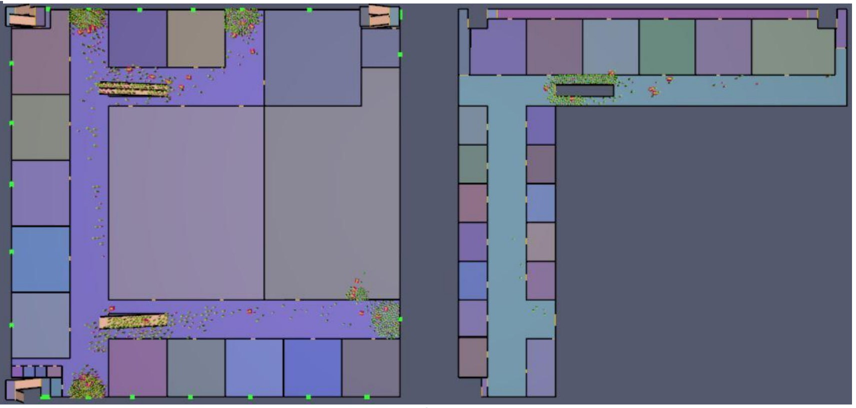
Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No
Door width: 20%



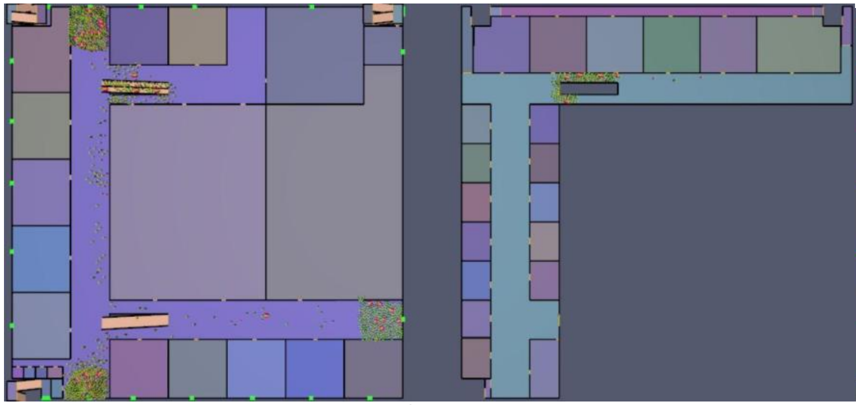
Occupant load: 0.125 person/m^2
Route choice: Go to closest
Physical distancing: No
Door width: 15%



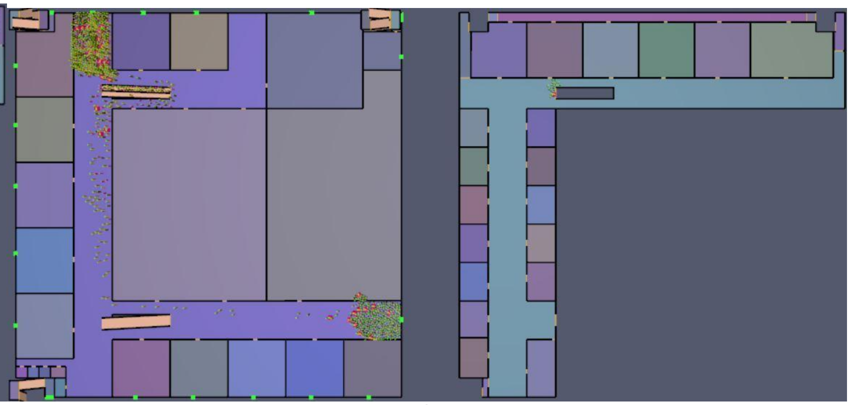
Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No
Door width: 30%



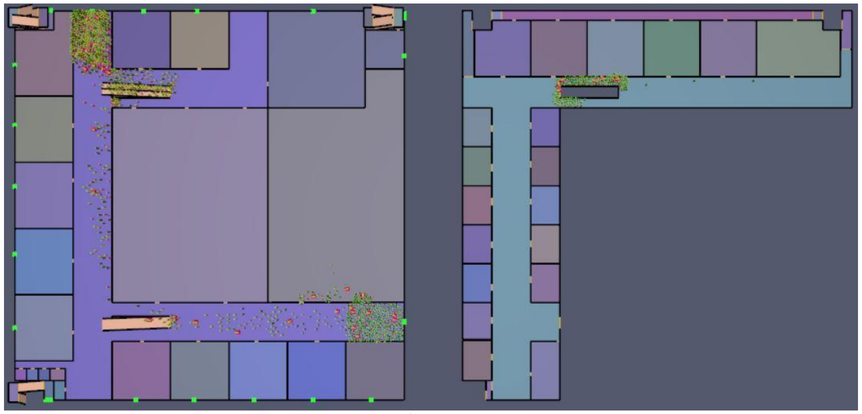
Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No
Door width: 25%



Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No
Door width: 20%



Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No
Door width: 15%



Occupant load: 0.125 person/m^2
Route choice: Go to main
Physical distancing: No
Door width: 14%